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# Radiocarbon

An International Journal of Cosmogenic Isotope Research

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# RADIOCARBON

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*List of laboratories.* Our comprehensive list of laboratories appears annually. We ask all laboratory directors to provide their telephone, telex and fax numbers as well as their E-mail addresses. Changes in names or addresses, additions or deletions should also be reported to the Managing Editor.

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ANNOUNCEMENTS



*The Editors of RADIOCARBON regret to announce that the publication of the Proceedings of the 13th International Radiocarbon Conference, Dubrovnik, Yugoslavia, Volume 31, Number 3, 1989, has been delayed. We are making every effort to rectify this situation.*

**FROM THE EDITOR**  
**GAINING ON GUTENBERG**

Although you may not be able to tell the difference from the first issue in the current volume, this second issue is another landmark for *RADIOCARBON*. With Volume 32, we began our larger format, nearly 80% larger printed area per page than the format for the first 31 volumes of this journal. Using “desktop publishing” technology, our staff prepared this issue entirely in-house. Thus eliminated are time-consuming and costly transcontinental trips the manuscripts have made for typesetting, proof correcting and final paging. Authors can expect faster publication, easier corrections and the opportunity for late modifications to manuscripts. We see this as a step toward better, tighter control over the quality of the output and a hedge against inflationary costs for the next few years.

The procedural change is, from the author’s and reader’s point of view, nearly invisible; but if you are interested in the details, read on. Immediately upon receipt, if the editor considers a manuscript to be of appropriate subject matter for *RADIOCARBON*, he will select reviewers, often in consultation with an associate editor. With advice from reviewers and associates, the editor decides whether to publish and how the manuscript must be modified. The next stage in the process is a dialogue between the authors and the managing editor, sometimes involving another iteration with reviewers that results in a mutually acceptable manuscript.

At this point, we request but do not require that the corresponding author submit the final manuscript in one of the acceptable word-processing formats as well as the traditional hard-copy version. Our program is WordPerfect 5.1, so naturally we would prefer any version of WordPerfect, if it is at all possible. Figures should be “camera-ready”. We will prepare “typeset” copy as it would appear in the journal and return this to the corresponding author for final inspection and last-chance corrections. The editors and authors share responsibility for quality of the final manuscript. The camera-ready copy then goes for the first time to “press” for reproduction, binding and distribution.

We now have only ourselves to blame for typographical errors.

Austin Long

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# Radiocarbon

1990

## ACCELERATOR MASS SPECTROMETRIC RADIOCARBON MEASUREMENTS ON FORAMINIFERA SHELLS FROM DEEP-SEA CORES

### SAMPLE PREPARATION

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### MASS SPECTROMETRY

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**ABSTRACT.** Radiocarbon ages determined by the AMS method on hand-picked foraminifera shells are reported. The results allow estimates of the ventilation rate of the deep Atlantic and Pacific Oceans during glacial time. They also extend our knowledge of the chronology of events associated with the transition from full glacial conditions ca 15,000 years ago to full interglacial conditions ca 8000 years ago. This and the previous lists (Broecker *et al* 1988c) contain all the results obtained as part of this program through the fall of 1989.

### INTRODUCTION

In this paper we present radiocarbon ages obtained by accelerator mass spectrometry (AMS) (Suter *et al* 1984) on hand-picked foraminifera shells from deep-sea cores. All the ages obtained as part of this program up to the fall of 1989 are included in either this or the previous list (Broecker *et al* 1988c). In the sections that follow, we comment on the results from particular cores or groups of cores. Note that none of the ages given here have been corrected for the reservoir age. Four hundred years should be subtracted from the planktonics if they are to be compared with ages for terrestrial plants.

### CEARA RISE

We studied a series of three cores taken at 2.8, 3.5 and 4.0km depths on the Ceara Rise in cooperation with Bill Curry of Woods Hole Oceanographic Institute (WHOI) in order to determine the surface-to-deep-water <sup>14</sup>C age difference for the glacial Atlantic. Broecker *et al* (1988a,b) published an interpretation of the results on one of these cores. We dated several species of planktonic forams as well as mixed benthics. Tables 1-3 list the abundance data and the <sup>14</sup>C ages.

<sup>1</sup>Currently at Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratories, Livermore, CA 94550

TABLE 1  
KNORR 110-82GC Equatorial Atlantic Ceara Rise  
Location (4°20.2'N, 43°29.2'W) Depth 2816m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No. tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
2128	25-28	14.5	<u>G sacc</u>	557	30.8	222	12.3	Jun 86	14,150±160
2652	"	"	<u>G ruber</u>	1010	22.8	500	11.3	Jan 87	13,870±260
2129	"	"	<u>P obliq</u>	38	2.0	254	13.2	Jun 86	12,610±140
2241	"	"	<u>N duter</u>	143	8.8	213	13.0	Jul 86	13,860±190
2130	"	"	<u>M benth</u>	5.8	0.24	233	9.5	Jun 86	14,930±200
2018	30-33	6.8	<u>G sacc</u>	215	14.9	194	13.5	Apr 86	15,100±250
4436	"	"	<u>G sacc</u>	215	14.9	167	7.6	Dec 88	15,080±120
2019	"	"	<u>G ruber</u>	526	10.1	453	8.7	Apr 88	15,450±260
4438	"	"	<u>G ruber</u>	526	10.1	938	8.4	Dec 88	15,130±120
	"	"	<u>P obliq</u>	5.7	0.36	-	-	-	-
2020	"	"	<u>N duter</u>	62	3.7	186	11.1	Apr 86	15,170±260
4437	"	"	<u>N duter</u>	62	3.7	212	8.8	Dec 88	14,820±120
2021	"	"	<u>M benth</u>	6.7	0.21	298	9.3	Apr 88	16,350±280
2651	35-38	7.4	<u>G sacc</u>	216	16.3	163	12.3	Jan 87	16,090±320
2650	"	"	<u>G ruber</u>	496	8.7	400	7.0	Jan 87	15,870±290
	"	"	<u>P obliq</u>	1.6	0.08	-	-	-	-
2244	"	"	<u>N duter</u>	58	3.5	229	13.7	Jul 86	16,060±220
2246	"	"	<u>M benth</u>	4.7	0.11	187	4.4	Jul. 86	16,130±240
2131	40-43	8.9	<u>G sacc</u>	220	15.5	183	13.0	Jun 86	16,710±250
2132	"	"	<u>G ruber</u>	458	13.2	548	15.8	Jun 86	17,040±250
	"	"	<u>P obliq</u>	1.4	0.07	-	-	-	-
2133	"	"	<u>N duter</u>	87	6.3	181	13.2	Jun 86	17,610±280
2134	"	"	<u>M benth</u>	4.5	0.23	193	10.2	Jun 86	17,870±370
2653	45-48	8.6	<u>G sacc</u>	186	22.8	86	9.5	Jan 87	17,780±360
2654	"	"	<u>G ruber</u>	766	14.0	500	12.7	Jan 87	17,430±340
	"	"	<u>P obliq</u>	4.2	0.22	-	-	-	-
2248	"	"	<u>N duter</u>	53	3.4	199	12.9	Jul 86	17,660±260
2249	"	"	<u>M benth</u>	4.5	0.23	155	5.8	Jul 86	17,900±640

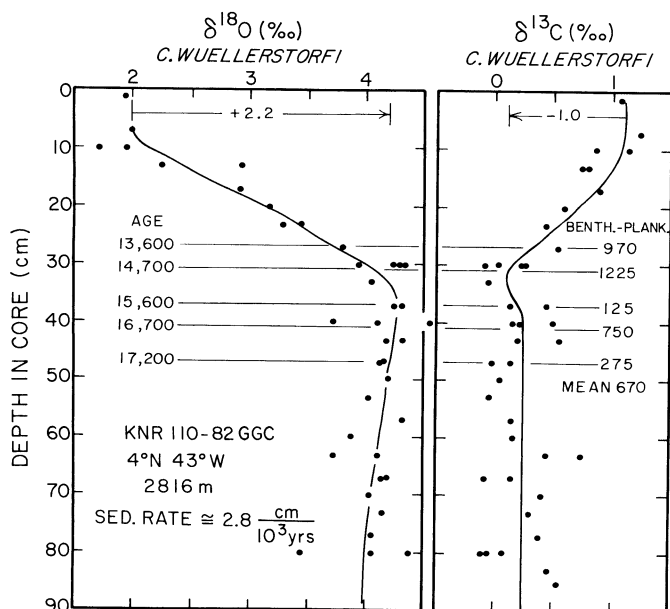


Fig 1. Oxygen and carbon isotope results for benthic foraminifera from Ceara Rise core KNR 110-82GGC (Curry *et al* 1988). This core comes from a depth of 2.8km. Shown on the left are mean  $^{14}\text{C}$  ages for planktonic foraminifera (corrected for a 400-yr age of surface-water carbon). Shown on the right are the benthic-planktonic age differences obtained for these same samples. The mean difference for five depth horizons is 670 yr. Note that glacial water at this site is depleted by ca 1.0‰ in  $^{13}\text{C}$  relative to that for the late Holocene.

TABLE 2  
KNORR 110-66GGC Equatorial Atlantic Ceara Rise  
Location ( $4^{\circ}33.8'\text{N}$ ,  $43^{\circ}22.9'\text{W}$ ) Depth 3547m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
5070	45-50	6.4	<i>G sacc</i>	262	16	157	9.6	Jun 89	16,450±150
5071	"	"	<i>N duter</i>	57	3.9	143	9.7	Jun 89	16,660±150
5072	"	"	<i>M benth</i>	4.7	0.08	496	8.9	Jun 89	17,030±150
5074	49-53	6.6	<i>G sacc</i>	297	20	131	8.8	Jun 89	16,800±150
5075	"	"	<i>N duter</i>	64	4.0	156	9.6	Jun 89	17,030±150
5073	"	"	<i>M benth</i>	5.2	0.11	348	7.6	Jun 89	17,690±150
5076	53-58	6.9	<i>G sacc</i>	250	15	148	8.9	Jun 89	18,130±160
5077	"	"	<i>N duter</i>	78	4.5	139	8.1	Jun 89	18,060±180
5078	"	"	<i>M benth</i>	4.2	0.08	351	6.9	Jun 89	18,630±180
5285	56-61	6.2	<i>G sacc</i>	232	13.4	156	9.0	Jul 89	18,860±190
5286	"	"	<i>N duter</i>	79	4.2	162	8.7	Jul 89	18,980±190
5284	"	"	<i>M benth</i>	3.6	0.06	336	8.0	Jul 89	19,540±220

Figures 1-3 give a summary of the benthic-planktonic age differences. The mean deep-water age differences obtained for all three cores is 650 years (based on 14 pairs). No significant difference exists in the age obtained for the three depths, *ie*, 670 yr at 2.8km, 520 yr at 3.5km and 720 yr at 4.0km.

As shown in the tables, the abundance of *G sacculifer* is three times lower in the deep core than in the shallower ones, whereas that of *N dutertrei* is somewhat higher. As the cores are from nearly the same location, we would logically attribute this deficiency of *G sacculifer* to preferential dissolution and shell breakup. Coupled with bioturbation, this should lead to a younger age for *G sacculifer* than for *N dutertrei*. However, we see only small age differences at all depths (average of 45 yr at 2.8km, 122 yr at 3.5km and 120 yr at 4.0km). In particular, we see no increase in this age difference at 4.0km where the abundance of *G sacculifer* relative to that of *N dutertrei* is much lower.

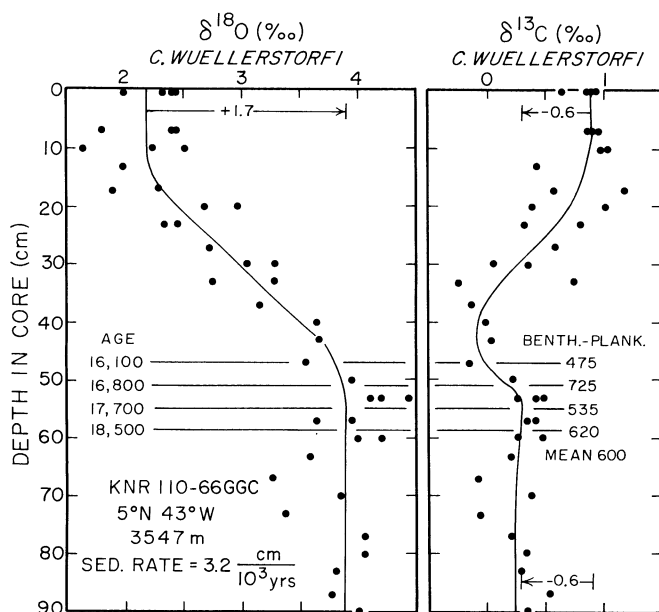


Fig 2. Oxygen and carbon isotope results for benthic foraminifera from Ceara Rise core KNR 110-66GGC (Curry *et al* 1988). The depth of this core is 3.5km. Shown on the left are mean  $^{14}\text{C}$  ages for planktonic foraminifera (corrected for a 400-yr age of surface-water carbon). Shown on the right are the benthic-planktonic age differences obtained on these same samples. The mean difference for four levels is 520 yr. Note that glacial water at this site is depleted by a ca 0.6‰ in  $^{13}\text{C}$  relative to that for the late Holocene.

TABLE 3  
KNORR 110-50GGC Equatorial Atlantic Ceara Rise  
Location (4°51.9'N, 43°12.3'W) Depth 3995m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
4786	17-20	5.9	<u>G_sacc</u>	134	8.4	133	8.3	Apr 89	13,580±140
5219	"	"	<u>N_duter</u>	128	7.1	178	9.9	Apr 89	14,710±140
4787	"	"	<u>M_benth</u>	10.5	0.16	453	7.0	Apr 89	15,040±140
4783	20-23	4.8	<u>G_sacc</u>	62	2.7	169	7.3	Apr 89	13,850±130
4784	"	"	<u>N_duter</u>	64	3.3	152	7.8	Apr 89	14,500±200
4785	"	"	<u>M_benth</u>	7.3	0.13	417	7.3	Apr 89	14,760±140
4772	22-27	4.5	<u>G_sacc</u>	98	5.0	169	8.6	Apr 89	16,900±170
4773	"	"	<u>N_duter</u>	95	5.1	162	8.7	Apr 89	16,740±210
4774	"	"	<u>M_benth</u>	4.9	0.08	361	5.7	Apr 89	17,110±190
4777	27-32	5.5	<u>G_sacc</u>	117	5.5	169	7.9	Apr 89	17,350±170
4778	"	"	<u>N_duter</u>	120	5.1	166	7.1	Apr 89	17,540±160
4779	"	"	<u>M_benth</u>	5.6	0.08	532	8.0	Apr 89	18,360±200
4780	31-36	5.5	<u>G_sacc</u>	119	6.5	138	7.5	Apr 89	18,210±190
4781	"	"	<u>N_duter</u>	128	7.1	142	7.9	Apr 89	18,620±200
4782	"	"	<u>M_benth</u>	6.1	0.08	605	8.3	Apr 89	19,110±190
5067	35-40	4.4	<u>G_sacc</u>	127	6.6	168	8.7	Apr 89	19,470±180
5068	"	"	<u>N_duter</u>	78	4.1	159	8.3	Apr 89	18,980±160
5069	"	"	<u>M_benth</u>	4.0	0.06	358	5.1	Apr 89	20,360±220

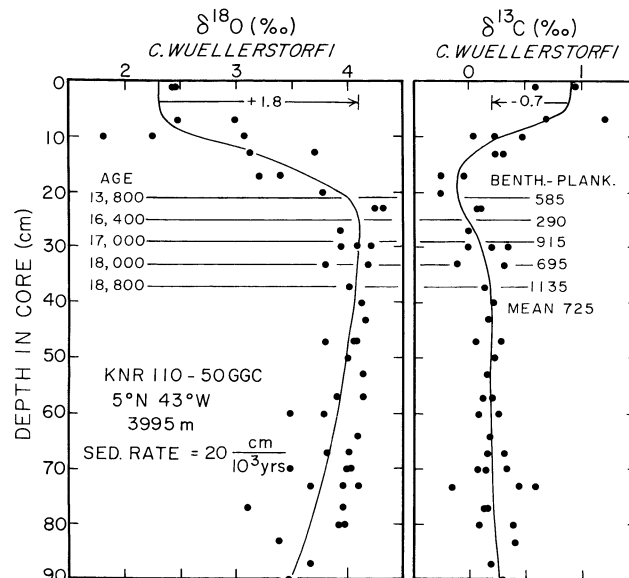


Fig 3. Oxygen and carbon isotope results for benthic foraminifera from Ceara Rise core KNR110-50GGC (Curry *et al* 1988). The depth of this core is 4.0km. Shown on the left are mean  $^{14}\text{C}$  ages for planktonic foraminifera (corrected for a 400-yr age for surface-water carbon). Shown on the right are the benthic-planktonic age differences obtained on these same samples. The mean difference for five pairs is 725 yr. Note that glacial water at this site is depleted by ca 0.7‰ in  $^{13}\text{C}$  relative to that for the late Holocene.

## CARIBBEAN SEA

We selected Core V28-122 as representative of the low nutrient and high  $^{13}\text{C}/^{12}\text{C}$  water of the intermediate depth Atlantic during glacial time (Oppo & Fairbanks 1987). As Figure 4 shows, the  $\delta^{13}\text{C}$  value for benthic forams was higher during glacial time than during the Holocene in contrast to the lower glacial values for the three Ceara Rise cores (see previous section). Although V28-122 comes from 3.6km depth, it is representative of water at ca 1.8km depth in the open Atlantic, *ie*, the sill depth for the Caribbean.

As Table 4 and Figure 4 show, the three glacial-age samples yield an average benthic-planktonic age difference of 180 years, as opposed to ca 650 years for the open Atlantic. Hence, as would be expected, the low nutrient-upper water of glacial time has a lower  $^{14}\text{C}$  age than the high nutrient-deep water of glacial time.

TABLE 4  
V28-122 Caribbean Sea Columbia Basin  
Location (11°56'N, 78°41'W) Depth 3623m

ETH no.	Depth (cm)	Coarse Fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
5058	106-114	5.9	<u>G sacc</u>	24	1.48	150	9.2	May 89	14,140±110
5059	"	"	<u>G ruber</u>	513	5.07	758	7.5	May 89	15,480±140
5060	"	"	<u>M benthic</u>	13	0.32	331	8.1	May 89	16,750±130
5063	115-123	7.4	<u>G sacc</u>	44	2.12	163	7.8	May 89	17,120±150
5061	"	"	<u>G ruber</u>	407	5.62	601	8.3	May 89	16,980±140
5062	"	"	<u>M benthic</u>	20	0.47	417	9.9	May 89	17,300±150
5227	125-128	6.0	<u>G sacc</u>	46	2.70	165	9.7	Jul 89	17,390±160
5226	"	"	<u>G ruber</u>	523	15.2	340	9.9	Jul 89	17,680±170
5225	"	"	<u>M benthic</u>	36	0.67	570	10.5	Jul 89	17,610±180
5454	127-139	-	Cibicides	-	-	229	5.5	Aug 89	18,370±200
5455	"	-	Miliolids	-	-	270	8.6	Aug 89	17,980±170
5453	"	-	Other benthics	-	-	267	10.2	Aug 89	18,730±190

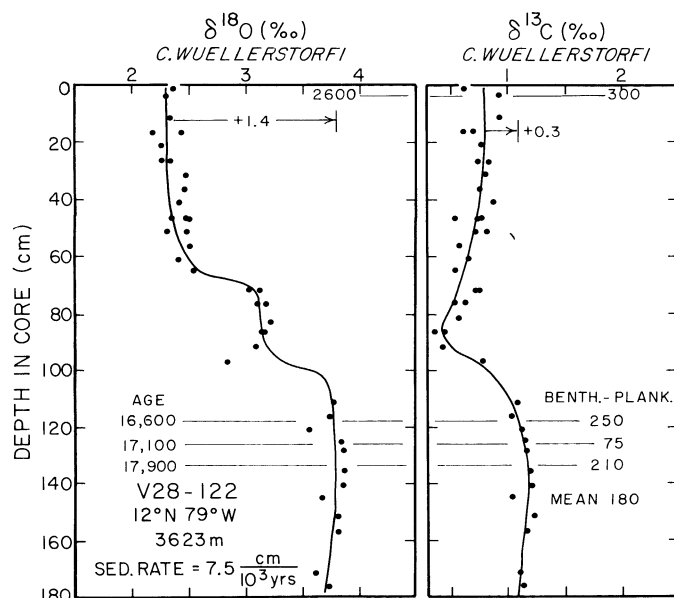


Fig 4. Oxygen and carbon isotope records for benthic forams from Caribbean core V28-122 (Oppo & Fairbanks 1987). Shown on the left are the average  $^{14}\text{C}$  ages for planktonic foraminifera (corrected for an assumed 400-yr age for surface water) and to the right are the differences between the benthic and planktonic age. Some of the ages are from this list (Table 4). The rest are from our previous list (Broecker *et al* 1988c). Note that the glacial water at this site is enriched by ca 0.3‰ in  $^{13}\text{C}$  relative to that for Holocene time indicating that the site of this core was bathed in low nutrient waters.



Two samples from the period of transition between full glacial and full interglacial time yield highly anomalous results. The age for *G sacculifer* is in both cases much younger than that for *G ruber* and the benthic-planktonic age difference is very large (Fig 5). We suspect that these anomalies relate to the abundance minimum for both planktonic species centered at 100cm depth (Fig 6). Both the ages of *G sacculifer* and of *G ruber* are influenced by the downward mixing of younger foraminiferal tests from shallower levels in the core.

We have another problem with this core. One of the original samples we analyzed came from 123-124cm depth (Broecker *et al* 1988c). It yielded nearly concordant planktonic ages averaging 15,700 years. As we found too few benthics in this sample, we had to pick more from slightly deeper levels. Two more problems exist. First, the benthic-planktonic age difference was larger (~700 yr) than that obtained for the three samples shown in Figure 5. Second, the ages were all ca 1500 years younger than those for the sample from 125-128cm. Hence, we exclude this result from Figure 4.

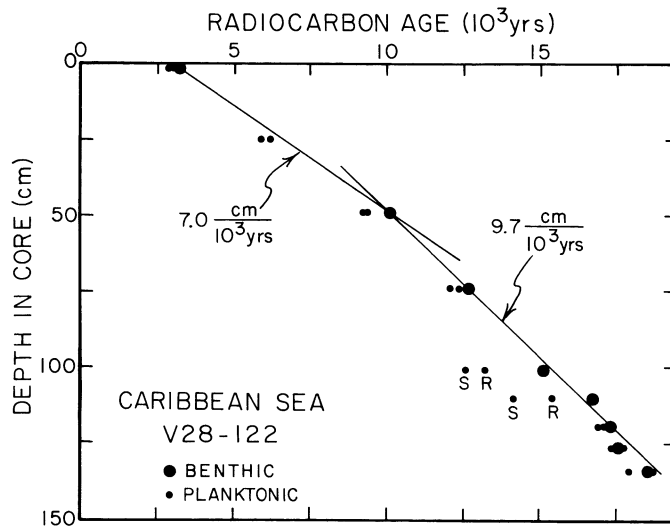


Fig 5.  $^{14}\text{C}$  age vs depth in Caribbean Sea core V28-122. The *G sacculifer* (S) and the *G ruber* (R) for two levels are anomalously young. These samples come from a horizon where the abundances are very low and therefore may be strongly influenced by the downward mixing of younger specimens (Fig 6).

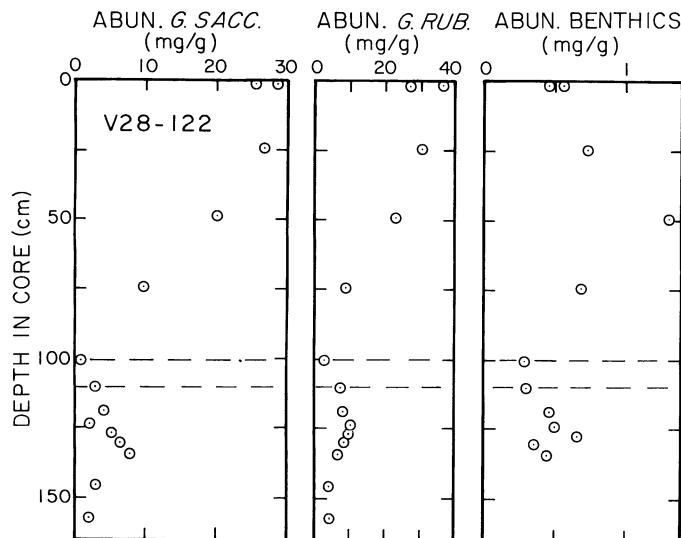


Fig 6. Abundance vs depth for the two planktonic and mixed benthic samples from Caribbean Sea core V28-122. The dashed lines represent the two levels yielding anomalously low planktonic ages (see Fig 5).

In an attempt to assess whether differences exist among the ages for individual species of benthic foraminifera, we divided one sample into three parts, one consisting of only *C wuellerstorfi*, one consisting of only miliolids and one consisting of the remainder of the benthics. As we see in Table 4, the three results spread by ca 2σ with the miliolids giving an 800 ± 300 year younger age than the non-miliolid-cibicides fraction. The age for the cibicides falls in between that for the other two fractions.

## ORCA BASIN

We determined radiocarbon ages on two cores from the Orca Basin in the Gulf of Mexico (Table 5, Fig 7). The purpose was to define the chronology of meltwater discharge from the Mississippi River. The results from EN32-PC4 suggest that meltwater discharge was greatly reduced during the period from ca 11,000 to ca 10,000 years ago. This is consistent with geologic evidence that the discharge of meltwaters via glacial Lake Agassiz was diverted from the Mississippi to the St Lawrence River ca 11,000 years ago and diverted back to the Mississippi ca 10,000 years ago. As summarized by Broecker *et al* (1989a), these results are consistent with the hypothesis that the Younger Dryas cold event was caused by a shutdown of the Atlantic's conveyor system caused by the increased meltwater flow via the St Lawrence River.

We redated one level in core EN32-PC6 to check several earlier results which gave anomalously young results, leading us to suspect that a hiatus existed in this core. The new date fits exactly with the results of core EN32-PC4 and suggests that some problem exists with the previous determinations. We have never before encountered such large differences between results generated by our AMS dating program. Further, as we ran the four anomalous samples at three different times spread over more than one year, the explanation cannot lie in a single episode of contamination.

TABLE 5  
Results on cores from the Orca Basin of the Gulf of Mexico

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
EN32-PC6 Orca Basin, Gulf of Mexico Location (26°57'N, 91°21'W) Depth 2280m									
4769	436-437	-	M plank	-	-	-	5.8	May 89	10,910±160
EN32-PC4 Orca Basin, Gulf of Mexico Location (26° 56'N, 91°22'W) Depth 2260m									
4767	94-96	-	M plank	-	-	-	7.9	Apr 89	9510±100
4194	144-146	-	"	-	-	-	6.2	Oct 88	10,490±90
4195	150-152	-	"	-	-	-	8.0	Oct 88	10,700±130
4196	164-166	-	"	-	-	-	8.2	Oct 88	11,030±90
4197	194-196	-	"	-	-	-	6.4	Oct 88	11,510±100
4198	214-216	-	"	-	-	-	8.0	Oct 88	12,450±90
4768	288-290	-	"	-	-	-	6.8	Apr 89	13,260±140
Gerg 87G13-31 Orca Basin, Gulf of Mexico Location (26° 56'N, 91° 21'W) Depth 2350m									
5447	330-335	0.8	M plank	-	-	-	9.3	Aug 89	10,570±110
5446	360-365	2.1	"	-	-	-	10.0	Aug 89	11,890±110
5449	480-485	0.5	"	-	-	-	8.8	Aug 89	14,380±140
5448	490-495	0.3	"	-	-	-	8.0	Aug 89	14,860±150

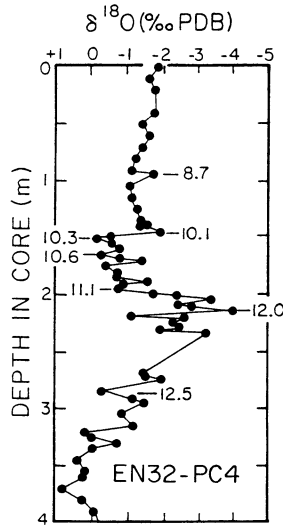


Fig 7. Plot vs depth of  $\delta^{18}\text{O}$  on white *G ruber* from two Orca Basin cores. Four seemingly anomalous ages for core EN 32-PC6 were replaced with a new one of 10,500 (corrected for a 400-yr surface-water age). This new age conforms with those for core EN32-PC4.

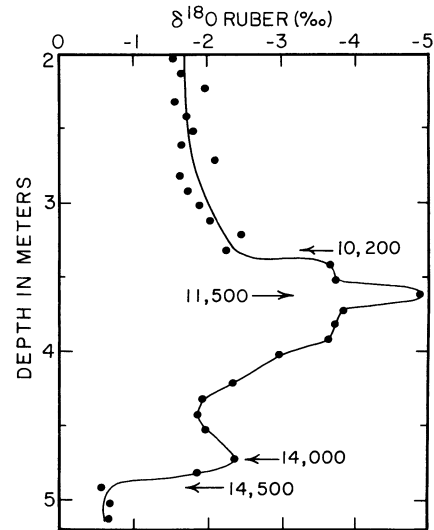
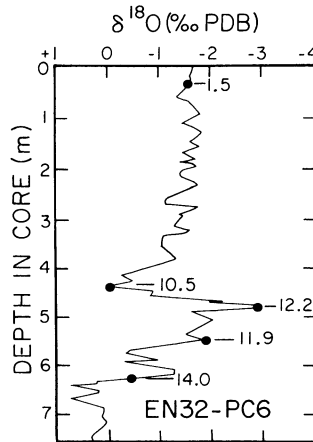


Fig 8. Oxygen isotope composition of *G ruber* as a function of depth in Texas A&M core 87G13-31 from the Orca Basin. The  $^{14}\text{C}$  ages have been corrected for an assumed 400-yr age for surface-water  $\Sigma\text{CO}_2$ .

Jim Brooks of Texas A&M obtained a set of four piston cores for us from the same site in the Orca Basin. Delia Oppo and Chris Charles conducted oxygen isotope analyses on one of these cores in the LDGO laboratory of Richard Fairbanks in order to locate the meltwater event. Figure 8 shows the results. Four  $^{14}\text{C}$  ages (Table 5) on mixed planktonics define the onset ( $\sim 14,300$  yr ago) and the termination ( $\sim 10,500$  yr ago) of this event.

#### CANARY ISLANDS RISE

Core V30-60 was selected to obtain a chronology for the pteropod preservation event seen in the early Holocene of the northern Atlantic. The results are listed in Table 6 and shown graphically in Figure 9. It is possible that this event was created by the increase in  $\text{CO}_3^{2-}$  ion concentration in the ocean associated with the drawdown in atmospheric  $\text{CO}_2$  content brought about by the early Holocene reforestation of the areas covered by ice and tundra during glacial time. As Figure 10 shows, the preservation event appears to correspond to an early Holocene minimum in atmospheric  $\text{CO}_2$  content.

TABLE 6  
 V30-60 North Atlantic in the vicinity of the Canary Islands  
 Location (25°41'N, 18°27'W) Depth 3177m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
4770	14-17	26.4	G_sacc	72.7	6.1	125	10.5	Apr 89	4650±80
4771	20-23	28.5	Pteropods	-	-	-	7.3	Apr 89	7680±170
4209	23-24	29.9	Pteropods	-	-	-	7.4	Oct 88	8460±70
4210	26-27	30.4	Pteropods	-	-	-	7.0	Oct 88	9380±80
4211	29-30	24.0	Pteropods	-	-	-	8.0	Oct 88	9550±80
4212	32-33	20.6	Pteropods	-	-	-	8.1	Oct 88	9340±80

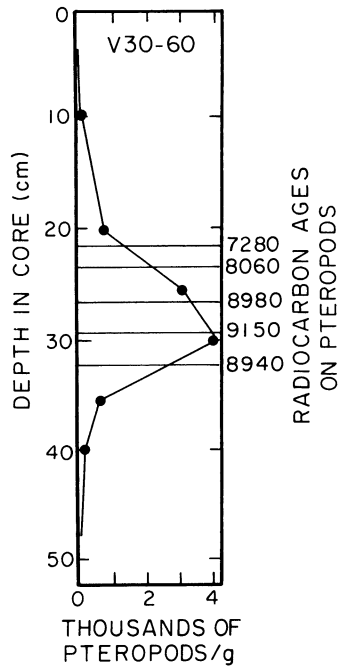


Fig 9. Pteropod abundance in Canary Islands Rise core V30-60 and AMS  $^{14}\text{C}$  ages on hand-picked pteropods from this core. The  $^{14}\text{C}$  ages are corrected for an assumed 400-yr air-sea difference.

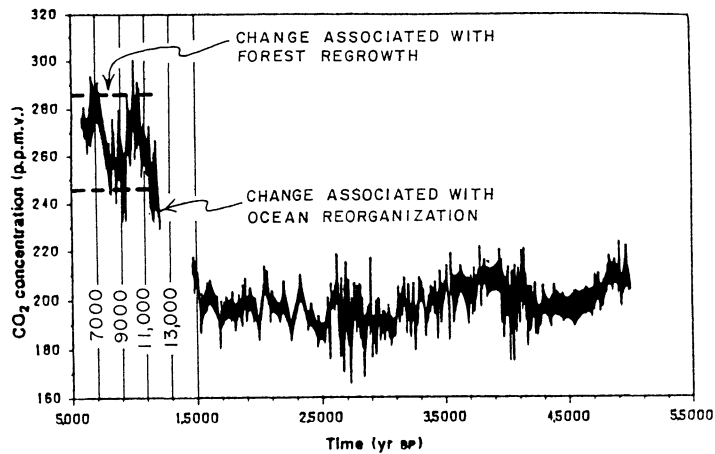


Fig 10.  $\text{CO}_2$  record for the Byrd Antarctica ice core (Neftel *et al* 1988). The time scale is based on the current accumulation rate of ice and flow modeling. The early Holocene dip dropped the  $\text{CO}_2$  content from ca 285 to ca 245  $\mu\text{atm}$ .

## NORTHERN ATLANTIC

In order to resolve the discordance between two previous measurements ( $11,300 \pm 140$  and  $10,230 \pm 200$ , Broecker *et al* 1988c), we repeated the analysis of *N pachyderma* (left coiling) from a depth of 157-158cm, the peak of the Younger Dryas cold period. The new analysis yielded a result of  $11,280 \pm 90$  years, confirming the first of the two previous results. Subtracting 400 years for the age of surface waters, we get 10,880 years for the Younger Dryas peak.

In a routine duplication, we dated one of the results published in our previous list (Broecker *et al* 1988c), *G bulloides* (V23-81, 172-173cm). The original sample run in August 1986 had an abundance of 3.6mg/gm and an age of  $11,860 \pm 170$  years. The new sample run in December 1988 had an abundance of 3.1mg/gm and an age of  $11,980 \pm 110$  years (Table 7).

TABLE 7  
V23-81 North Atlantic from the Ruddiman-McIntyre Triangle  
Location ( $54^{\circ}18'N$ ,  $16^{\circ}48'W$ ) Depth 2393m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No. tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
4193	157-158	8.7	<i>N pach</i> s	4130	40.4	787	7.7	Jul 88	$11,280 \pm 90$
4656	172-173	2.4	<i>G bull</i>	219	3.14	460	6.6	Feb 89	$11,980 \pm 110$

## RED SEA

Deuser and Degens (1969) showed that a marked transition in sediment diagenesis and in stable isotope ratio occurred in the Red Sea at the close of glacial time (Fig 11). Below this transition, pteropods are covered with thick coatings of secondary aragonite. The  $\delta^{18}O$  for these coatings is 6‰ higher than for Holocene pteropods and the  $\delta^{13}C$  is 3‰ higher (Fig 11). No forams are found below the boundary. We interpret these results to indicate hypersaline conditions in the Red Sea during glacial time. Working with Werner Deuser, we have attempted to establish more closely the date of the sharp transition from glacial to postglacial conditions (see Table 8 for results). Some of our results were published in our previous date list (Broecker *et al* 1988c); the rest are here. In Figure 12, we summarize these findings and show the best age estimate for termination of hypersaline conditions is ca 13,000 years.

## SOUTH CHINA SEA

We previously studied two cores, V35-5 and V35-6, from 2km depth in the southern part of the South China Sea with the purpose of determining the age of deep Pacific water during glacial time (Broecker *et al* 1988b). We encountered a problem - *P obliquiloculata* was consistently older than *G sacculifer*. Since no way existed to determine which if either of these age sets was correct, we sought another core. Gerd Liebezeit of the Hamburg University group provided samples from Sonne 50 37KL, a piston core from 2695m in the central part of the basin (Table 9). For the glacial section of this core, we found no consistent bias between the *P obliquiloculata* and *G sacculifer* ages. The mean benthic-planktonic age difference for three pairs is ca 1700 years. These results are discussed in a separate publication (Broecker *et al*, in press).

TABLE 8  
Results on Red Sea cores

ETH no.	Depth (cm)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No. tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
Ch61-118K Red Sea Location (21° 14.4'N, 38° 4.3'E) Depth 1989m								
3811	165-170	Pteropods >1000 $\mu\text{m}$	-	--	--	7.5	May 88	11,980 $\pm$ 120
3812	165-170	Pteropods 250-1000 $\mu\text{m}$	-	--	--	10.2	May 88	11,520 $\pm$ 100
3813	170-175	Pteropods > 1000 $\mu\text{m}$	-	--	--	10.6	May 88	13,420 $\pm$ 110
Ch61-119K Red Sea Location (21° 16.8'N, 38° 1.4'E) Depth 2175m								
4451	145-150	<u>G sacc</u>	-	--	--	8.3	Dec 88	8770 $\pm$ 90
4452	215-220	Pteropods > 1000 $\mu\text{m}$	-	--	--	8.2	Dec 88	13,640 $\pm$ 110
4453	235-240	Pteropods > 1000 $\mu\text{m}$	-	--	--	7.1	Dec 88	15,780 $\pm$ 140

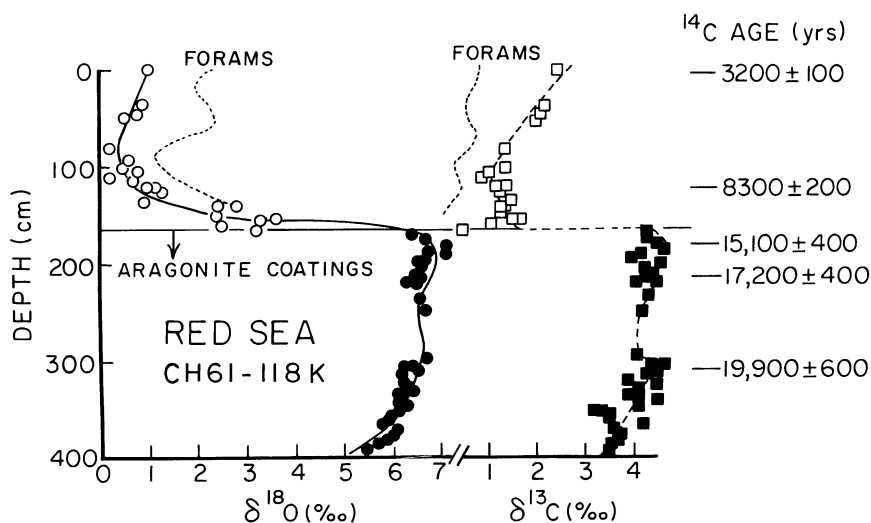


Fig 11. Oxygen and carbon isotope records on pteropods from Red Sea core CH61-118K (Deuser & Degens 1969; Ku, Thurber & Mathieu 1969).  $\circ$  = pteropods free of secondary coatings.  $\bullet$  = pteropods heavily coated with secondary aragonite. Also shown are decay counting  $^{14}\text{C}$  ages obtained previously on bulk material (Ku, Thurber & Mathieu 1969).

TABLE 9  
SONNE 50 37KL South China Sea  
Location (18°55'N, 115°45'E) Depth 2695m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
5222	8-13	5.1	<u>G_sacc</u>	3.0	0.15	191	9.4	Jul 89	2040±70
5221	"	"	<u>P_obliq</u>	22.7	1.40	170	10.5	Jul 89	2430±60
5223	"	"	<u>M_benth</u>	9.3	0.26	238	6.6	Jul 89	3970±80
4440	40-45	7.7	<u>G_sacc</u>	34.5	1.35	197	6.5	Dec 88	5960±80
4439	"	"	<u>P_obliq</u>	22.0	9.82	164	7.3	Dec 88	6510±80
4441	"	"	<u>M_benth</u>	17.3	0.22	514	6.5	Dec 88	8270±100
5390	60-65	5.5	<u>G_sacc</u>	55.8	2.59	164	7.6	Aug 89	8500±110
5391	"	"	<u>P_obliq</u>	70.7	3.78	185	9.9	Aug 89	8500±110
5389	"	"	<u>M_benth</u>	17.5	0.29	526	8.6	Aug 89	10,030±120
4445	80-85	7.1	<u>G_sacc</u>	77.1	2.97	166	6.4	Dec 88	10,560±100
4446	"	"	<u>P_obliq</u>	116	4.68	171	6.9	Dec 88	10,620±120
4447	"	"	<u>M_benth</u>	14.2	0.22	488	7.4	Dec 88	11,890±110
4655	120-125	5.2	<u>G_sacc</u>	119	4.60	176	6.8	Feb 89	13,940±120
4654	"	"	<u>P_obliq</u>	17.5	0.68	166	6.4	Feb 89	13,240±120
----	"	"	<u>M_benth</u>	20.0	0.29	553	7.9	-	Lost
3807	155-160*	6.7	<u>G_sacc</u>	90.8	3.66	328	13.2	May 88	12,730±140
3806	"	"	<u>P_obliq</u>	128	5.01	267	10.5	May 88	12,290±250
3808	"	"	<u>M_benth</u>	8.3	0.23	396	11.0	May 88	13,710±120
5440	160-165	2.3	<u>G_sacc</u>	30.3	1.44	179	8.5	Aug 89	15,140±150
5441	"	"	<u>P_obliq</u>	12.1	0.65	148	7.9	Aug 89	15,300±150
5444	"	"	<u>M_benth</u>	11.6	0.23	466	9.4	Aug 89	17,100±220
4650	165-170	2.2	<u>G_sacc</u>	9.8	0.49	159	8.0	Feb 89	15,490±110
4651	"	"	<u>P_obliq</u>	16.8	0.78	171	7.9	Feb 89	15,590±160
-----	"	"	<u>M_benth</u>	12.6	0.16	575	7.2	-	Lost
4204	175-180	2.4	<u>G_sacc</u>	9.0	0.46	165	8.5	Oct 88	15,910±110
4205	"	"	<u>P_obliq</u>	17.3	0.73	179	7.6	Oct 88	15,890±120
4203	"	"	<u>M_benth</u>	14.5	0.21	628	9.1	"	17,430±140
4207	185-190	3.2	<u>G_sacc</u>	11.2	0.48	189	8.1	Oct 88	16,000±120
----	"	"	<u>P_obliq</u>	19.5	0.79	178	7.2	-	Lost
5065	"	"	<u>P_obliq</u>	19.5	0.79	210	7.1	May 89	16,860±150
4206	"	"	<u>M_benth</u>	14.3	0.26	462	8.5	Oct 88	17,590±140
4449	195-200	2.9	<u>G_sacc</u>	9.7	0.30	228	7.1	Dec 88	17,460±160
4450	"	"	<u>P_obliq</u>	18.3	0.76	203	8.4	Dec 88	17,270±150
4448	"	"	<u>M_benth</u>	16.2	0.20	613	7.5	Dec 88	18,940±160
5437	205-210	2.8	<u>G_sacc</u>	2.4	1.27	180	9.5	Aug 89	17,660±180
5438	"	"	<u>P_obliq</u>	7.3	0.38	146	7.5	Aug 89	17,255±190
5439	"	"	<u>M_benth</u>	15.6	0.23	815	12.1	Aug 89	19,445±190

\*Error in depth? Age fits better if 105-110 cm.

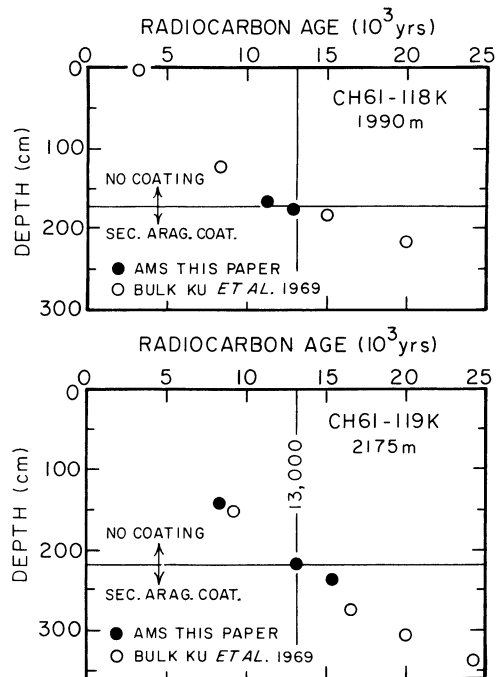


Fig 12.  $^{14}\text{C}$  ages (corrected for a 400-yr age for surface-water) vs depth in two Red Sea cores previously studied by Deuser and Degens (1969). In both, the transition from conditions conducive to the generation of thick secondary coatings abruptly ended ca 13,000 years ago.

#### SULU BASIN

In searching for the source of the age differences between *P. obliquiloculata* and *G. sacculifer* observed in core V35-5 in the South China Sea, we chose core V24-135 in the Sulu Sea. Rather than shedding light on the problem, these samples yielded large age differences for which we have no satisfactory explanation (Table 10) (see Broecker *et al* 1989b, for discussion).

TABLE 10  
V24-135 Sulu Basin, Sulu Sea  
Location (07°21'N, 120°21'E) Depth 4276m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
3794	101-102	22.9	<u>G.sacc</u>	272	17.3	170	10.8	May 88	14,410±160
4039	"	"	<u>G.sacc</u>	272	22.0	100	8.1	Jul 88	14,650±130
3795	"	"	<u>P.obliq</u>	78.3	3.01	323	12.4	May 88	10,660±130
4038	"	"	<u>P.obliq</u>	78.3	2.2	289	8.1	Jul 88	10,390±100
3797	110-111	31.3	<u>G.sacc</u>	156	10.3	170	11.2	May 88	17,870±160
3796	"	"	<u>P.obliq</u>	56.1	2.97	100	5.3	May 88	16,320±150
3799	119-120	5.6	<u>G.sacc</u>	29.4	1.55	232	12.2	May 88	13,940±140
3798	"	"	<u>P.obliq</u>	28.2	1.17	200	8.3	May 88	11,670±110
3805	131-133	10.4	<u>G.sacc</u>	101	8.02	200	15.9	May 88	20,670±210
3804	"	"	<u>P.obliq</u>	16.8	0.66	154	6.0	May 88	21,060±220
3809	141-142	27.2	<u>G.sacc</u>	139	8.46	215	13.1	May 88	19,220±210
3810	"	"	<u>P.obliq</u>	32.1	1.43	157	7.0	May 88	18,750±170



## MOROTAI BASIN

In yet another attempt to assess the age difference between *P obliquiloculata* and *G sacculifer* found in South China Sea core V35-5, we measured two pairs in core V33-88 from the Morotai Basin in the Philippine Sea (Table 11). Although in both cases *P obliquiloculata* was older than *G ruber*, the age differences of 300 and 210 years lie within the error of measurement. Since insufficient benthics were available in these samples for dating, we abandoned study of this core.

TABLE 11  
V33-88 Morotai Basin, Philippine Sea  
Location (2°42'N, 127°50'E) Depth 3237m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
-	135-136	9.7	<u>G_sacc</u>	55.6	1.21	137	4.4	-	Lost
3708	"	"	<u>G_ruber</u>	491	5.62	600	5.5	Mar 88	13,050±110
3699	"	"	<u>P_obliq</u>	296	8.03	297	8.0	Mar 88	13,350±120
-	155-156	8.3	<u>G_sacc</u>	6.2	0.22	92	4.5	-	Lost
3710	"	"	<u>G_ruber</u>	236	2.25	740	7.8	Jul 88	14,180±120
3701	"	"	<u>P_obliq</u>	150	4.31	428	8.2	Jul 88	14,370±150

## EAST PACIFIC RISE

As a check on the reproducibility of our results, we repeated the analysis of two samples published in our previous list (Table 12). They were from 34-36cm in core TT154-10. For *G sacculifer*, we obtained  $16,630 \pm 140$  years for a repick of a sample which previously had given  $16,600 \pm 340$  years. For *P obliquiloculata*, we obtained  $16,890 \pm 140$  years for a repick of a sample that had previously yielded an age of  $16,530 \pm 340$ .

TABLE 12  
TT154-10 (Core 5) East Pacific Rise  
Location (10°17.5'N, 111°20'W) Depth 3225m

ETH no.	Depth (cm)	Coarse fraction (%)	Foram sp	Abund (no/gm)	Abund (mg/gm)	No tests analyzed	Weight analyzed (mg)	Date of AMS analysis	Age (yr)
4434	34-36	47.5	<u>G_sacc</u>	-	-	-	8.6	Dec 88	16,630±140
4435	"	"	<u>P_obliq</u>	-	-	-	7.5	Dec 88	16,890±140

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## ISOTOPE-RATIO AND BACKGROUND CORRECTIONS FOR ACCELERATOR MASS SPECTROMETRY RADIOCARBON MEASUREMENTS

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ABSTRACT. We present here the method we use to convert to radiocarbon ages (<sup>14</sup>C/<sup>13</sup>C) ratios measured in the Arizona Accelerator Mass Spectrometer facility. We describe the procedures we use to convert sample and standard isotope ratios to values appropriate for calculation of radiocarbon ages. We also discuss, in some detail, corrections to account for sample contamination.

### INTRODUCTION

At the Arizona Accelerator Mass Spectrometry (AMS) facility, radiocarbon ages are determined by measuring the ratio (<sup>14</sup>C/<sup>13</sup>C) in a sample and comparing that ratio with a similar one measured for known standards (Linick *et al* 1986). The measured ratios of standards and samples are corrected to values corresponding to  $\delta^{13}\text{C} = -25\text{‰}$  using (<sup>13</sup>C/<sup>12</sup>C) ratios measured in a stable isotope mass spectrometer and the "fraction of modern," F, of the sample, S, is deduced from the equation

$$F = \frac{(\text{14/13})_{\text{S}[-25]}}{(\text{14/13})_{1950[-25]}} . \quad (1)$$

In this equation, isotope ratios are indicated by the ratio of isotope mass numbers, and the  $\delta^{13}\text{C}$  to which the ratio has been normalized is given by the number in square brackets. For example, the <sup>14</sup>C/<sup>13</sup>C of a sample, S, normalized to  $\delta^{13}\text{C} = -25\text{‰}$ , is given as (<sup>14</sup>/13)<sub>S[-25]</sub>. This notation is used throughout this paper.

The radiocarbon age of the sample, S, is calculated from the equation

$$\text{Radiocarbon Age} = -\tau \ln F , \quad (2)$$

where  $\tau$  is the Libby mean life (8033 years). In the following paragraphs we describe the conversion of measured isotope ratios to forms that can be used in equations (1) and (2). The method of measuring isotope ratios and the errors in such measurements are described by Linick *et al* (1986). Under Contamination Corrections, below, we present the form of background corrections applied to isotope ratios measured in our laboratory.

### ISOTOPE-RATIO CALCULATIONS

According to Stuiver and Polach (1977), most radiocarbon laboratories calculate the radiocarbon age of a sample, S, from the equation

<sup>1</sup>Deceased

$$\text{Radiocarbon Age} = -8033 \ln \frac{A_{\text{SN}}(1950)}{A_{\text{ON}}(1950)} \quad (3)$$

where  $A_{\text{SN}}$  is the specific activity of the sample,  $A_{\text{S}}$ , normalized to  $\delta^{13}\text{C} = -25\text{‰}$  by the equation

$$A_{\text{SN}} = A_{\text{S}} \left\{ \frac{1 - \frac{25}{1000}}{\delta^{13}\text{C}_{\text{S}}} \right\}^2 \quad (4)$$

$A_{\text{ON}}$  is a standard specific activity obtained from the specific activity, today, of NBS "old" oxalic acid (SRM 4990 B) normalized to  $\delta^{13}\text{C} = -19\text{‰}$ , using the equation

$$A_{\text{ON}} = 0.95 A_{\text{OX}} \left\{ \frac{1 - \frac{19}{1000}}{\delta^{13}\text{C}_{\text{OX}}} \right\}^2 \quad (5)$$

The numbers (1950) in Eq (3) indicate that specific activities should be measured in AD 1950, and the resultant age will be in radiocarbon years before present (BP), where present is the year AD 1950. Since both specific activities have the same decay rate, it is in fact, only necessary to measure the numerator and denominator of the logarithm at approximately the same time.

The normalized standard specific activity,  $A_{\text{ON}}$ , is related to the absolute international standard specific activity,  $A_{\text{abs}}$ , by the equation

$$A_{\text{abs}} = A_{\text{ON}} e^{+\lambda(y-1950)} \quad (6)$$

where  $y$  is the year of measurement and  $1/\lambda = 8267$  years. Since  $A_{\text{abs}}$  is the specific activity of a hypothetical (1950) atmospheric carbon level normalized to  $\delta^{13}\text{C} = -25\text{‰}$  (Stuiver & Polach 1977),  $A_{\text{ON}}$  is the specific activity of that hypothetical 1950 atmosphere with  $\delta^{13}\text{C} = -25\text{‰}$ , decayed to the present. In the following discussion, we label  $A_{\text{ON}}$  as  $A_{1950[-25]}$  to indicate that it is a specific activity, normalized to  $\delta^{13}\text{C} = -25\text{‰}$  which, when used in Eq (3) with a coincidentally measured and appropriately normalized sample specific activity,  $A_{\text{SN}}$ , yields a conventional radiocarbon age in years before AD 1950.

In a later paper, Stuiver (1983) presents results of a series of experiments relating the specific activities of "old" oxalic acid and "new" oxalic acid, NOX (NBS SRM 4990 C). These results can be summarized as

$$0.95 A_{\text{OX}[-19]} = 0.7459 A_{\text{NOX}[-25]} \quad (7)$$

where the numbers in square brackets are the  $\delta^{13}\text{C}$  values to which the activities are normalized. The results of Eqs (5) and (7) and the discussion in the paragraph above are combined to give

$$A_{1950[-25]} = 0.95 A_{\text{OX}[-19]} = 0.7459 A_{\text{NOX}[-25]} \quad (8)$$

In what follows, we will deduce equations equivalent to Eqs (4) and (8) for use in Eqs (1) and (2) when isotope ratios are measured instead of specific activities.

Specific activity is proportional to the ratio of  $^{14}\text{C}$  atoms to total carbon atoms in a sample or standard, so that Eq (8) can be written as

$$\left(\frac{14}{12+13}\right)_{1950[-25]} = 0.95 \left(\frac{14}{12+13}\right)_{\text{OX}[-19]} = 0.7459 \left(\frac{14}{12+13}\right)_{\text{NOX}[-25]} \quad (9)$$

To better than one part in  $10^4$ , the ratios in Eq (9) can be approximated as  $(14/12+13) = (14/12)$ , and

$$(14/12)_{1950[-25]} = 0.95 (14/12)_{\text{OX}[-19]} = 0.7459 (14/12)_{\text{NOX}[-25]} \quad (10)$$

If one measures  $(14/12)$  ratios, Eq (10) is the equation to be used to obtain the denominator of Eqs (1) and (2) from measurements on NBS oxalic acid standards. However, at Arizona, we measure  $(14/13)$  ratios, so that Eq (10) must be further modified. This modification is made by noting that for a sample, S,

$$(14/12)_S = (14/13)_S (13/12)_S = (14/13)_S \left(1 + \frac{\delta^{13}\text{C}_S}{1000}\right) (13/12)_{\text{PDB}} \quad (11)$$

where PDB is a reference standard, so that Eq (10) becomes

$$(0.975) (14/13)_{1950[-25]} = (0.95) (0.981) (14/13)_{\text{OX}[-19]} = 0.7459 (0.975) (14/13)_{\text{NOX}[-25]}$$

or

$$(14/13)_{1950[-25]} = 0.9558 (14/13)_{\text{OX}[-19]} = 0.7459 (14/13)_{\text{NOX}[-25]} \quad (12)$$

Finally, we wish to change the third term of Eq (12) to reflect the fact that in our laboratory we measure  $(14/13)_{\text{NOX}}$  with  $\delta^{13}\text{C} = -17.8\text{‰}$ . To do this, we use Eq (1) in Stuiver (1983), namely

$$A_{\text{NOX}[-25]} = A_{\text{NOX}[-17.8]} \left\{ \frac{0.975}{0.982} \right\}^2 \quad (13)$$

which relates specific activities for new oxalic acid for  $\delta^{13}\text{C} = -25\text{‰}$  and  $-17.8\text{‰}$ . As pointed out above, specific activities are essentially equal to  $(14/12)$  ratios and the square of the bracketed term in Eq (13) reflects the fact that to change from a  $(14/12)$  ratio (or specific activity) normalized to a particular value of  $\delta^{13}\text{C}$  to the  $(14/12)$  ratio with a different value of  $\delta^{13}\text{C}$ , one must apply the appropriate correction twice. However, to make a similar change to  $(14/13)$  ratios, one must apply the isotope correction only once, so that

$$(14/13)_{\text{NOX}[-25]} = \frac{\left(1 - \frac{25}{1000}\right)}{\left(1 - \frac{17.8}{1000}\right)} (14/13)_{\text{NOX}[-17.8]} = \left(\frac{0.975}{0.9822}\right) (14/13)_{\text{NOX}[-17.8]} \quad (14)$$

giving, from Eq (12)

$$(14/13)_{1950[-25]} = 0.9558 (14/13)_{\text{OX}[-19]} = 0.7404 (14/13)_{\text{NOX}[-17.8]} \quad (15)$$

Thus, the denominator of Eq (1) is obtained by measuring the (14/13) ratios of “old” and/or “new” oxalic acid and multiplying them by the appropriate factors from Eq (15) to obtain  $(14/13)_{1950[-25]}$ . In practice, we measure (14/13) for both OX and NOX for every target-wheel loading, and calculate an average  $(14/13)_{1950[-25]}$ . To verify proper operation of the instrument, we also obtain the ratio of  $(14/13)_{\text{NOX}[-17.8]}$  and  $(14/13)_{\text{OX}[-19]}$ , which, as can be seen from Eq (16), should be equal to 1.2909.

The numerator for Eq (1) is obtained by correcting the measured (14/13) ratio of a sample with  $\delta^{13}\text{C}_s$ , that is  $(14/13)_{\text{S}[\delta]}$ , by an equation of the form of Eq (14), namely:

$$(14/13)_{\text{S}[-25]} = (14/13)_{\text{S}[\delta]} \left[ \frac{1 - \frac{25}{1000}}{1 + \frac{(\delta^{13}\text{C})_s}{1000}} \right] \quad (16)$$

This is the exact form of an equation that was presented as an approximation in Linick *et al* (1986).

To obtain a radiocarbon age from measured (14/13) isotope ratios that is equivalent to the age one would obtain by measuring specific activities and using Eq (3): (a) measured values of  $(14/13)_{\text{OX}[-19]}$  and  $(14/13)_{\text{NOX}[-17.8]}$  are converted to  $(14/13)_{1950[-25]}$  using Eq (15); (b)  $(14/13)_{\text{S}[\delta]}$  ratios are converted to  $(14/13)_{\text{S}[-25]}$  using Eq (16); and (c) results from (a) and (b) are used in Eq (1) and (2). When this is done, we obtain

$$\text{Radiocarbon Age} = -\tau \ln \left\{ \frac{\left[ \frac{0.975}{1 + \frac{\delta^{13}\text{C}_s}{1000}} \right] (14/13)_{\text{S}[\delta]}}{(0.9558) (14/13)_{\text{OX}[-19]}} \right\} \quad (17a)$$

or

$$\text{Radiocarbon Age} = -\tau \ln \left\{ \frac{\left[ \frac{0.975}{1 + \frac{\delta^{13}\text{C}_s}{1000}} \right] (14/13)_{\text{S}[\delta]}}{(0.7404) (14/13)_{\text{NOX}[-17.8]}} \right\} \quad (17b)$$

## CONTAMINATION CORRECTIONS

A correction is necessary in AMS radiocarbon measurements because samples acquire a small amount of contamination, generally called background, in the process of converting them from their initial form to graphite. There is probably also an instrument background, but at the present time, the instrument background correction is much less than the contamination correction, and is included as part of the contamination correction. In the discussion that follows, we assume that all isotope ratios are corrected to  $\delta^{13}\text{C} = -25\text{‰}$ , and the square-bracketed subscripts used to indicate  $\delta^{13}\text{C}$  of isotope ratios are not included.

To determine the magnitude of the contamination correction, blank targets are made from material containing no  $^{14}\text{C}$  and measurements are made of the quantity

$$f = \frac{(14/13)_B}{(14/13)_{\text{std}}} = \frac{(14/\text{sec})_C}{(13/\text{sec})_C + (13/\text{sec})_M} \quad (18)$$

where the subscripts B, C, and std signify blank, contamination and standard quantities, and M denotes the matrix material of the blank target. The matrix material usually used to produce blank targets is graphite provided by the National Institute of Standards and Technology (NIST, formerly NBS). The use of this material allows us to: (a) determine the amount of  $^{14}\text{C}$  in the original graphite, (b) combust the graphite to  $\text{CO}_2$  and reconvert the  $\text{CO}_2$  to graphite in our sample preparation lines, and (c) measure the  $^{14}\text{C}$  in the processed graphite. The amount of  $^{14}\text{C}$  per gram of graphite observed in (a) is approximately one-fifth of that determined in (c).

The actual value of the quantity,  $f$ , in Eq (18) depends on the choice of standard material. For convenience, we use as a standard the ratio  $(14/13)_{1950[-25]}$ . This is often referred to as the  $(14/13)$  ratio of modern material, and its value in terms of the  $(14/13)$  ratios of the NBS oxalic acids is given in Eq (15). Multiple measurements over many months using many different blank targets yield values for  $f$  and its standard deviation for a one-milligram blank sample of

$$f = \left\{ \frac{(14/13)_B}{(14/13)_{1950}} \right\}_{\text{one-milligram blank}} = 0.004 \pm 0.001 .$$

The standard deviation is deduced from the scatter about their mean of many measurements on different blank samples. It is larger than the standard deviation one would obtain from pure counting statistics and includes the spread of values of  $f$  resulting from small variations in contamination during target preparation. Nevertheless, this standard deviation is assumed to represent the statistical distribution of measured values of  $f$  about their mean value.

Measurements of the quantity,  $f$ , on blank samples of various masses indicate that, as a function of mass,  $M$ ,

$$f(M) = \frac{f(\text{one mg})}{M} = \frac{0.004 \pm 0.001}{M}$$



where  $M$  is the mass of the sample in milligrams. For example, for a 100-microgram sample,

$$f(100\mu\text{g}) = 0.04 \pm 0.01 .$$

This dependence is just what one would expect if the mass of contaminant introduced during target fabrication was constant, independent of the size of the sample itself.

To describe the manner in which isotope ratios are corrected for contamination, consider the measured ratio,  $(14/13)_m$ , for a sample  $S$ ,

$$(14/13)_m = \frac{(14/\text{sec})_s + (14/\text{sec})_c}{(13/\text{sec})_s + (13/\text{sec})_c} , \quad (19)$$

where  $S$  and  $C$  denote isotopes from the sample and contaminative materials, respectively. This equation can be rewritten as

$$(14/13)_m = (14/13)_s \frac{\left\{ 1 + \frac{(14/\text{sec})_c}{(14/\text{sec})_s} \right\}}{1 + \frac{(13/\text{sec})_c}{(13/\text{sec})_s}} . \quad (20)$$

Before rewriting Eq (20), we introduce the assumption that the contaminating material is modern (1950) material. We show in the appendix that this is not a necessary assumption, but its introduction simplifies the considerations that follow. With this assumption, namely that  $(14/13)_c = (14/13)_{1950}$ , the quantity,  $f$ , defined in Eq (18), can also be written as

$$f = \frac{(13/\text{sec})_c}{(13/\text{sec})_c + (13/\text{sec})_M} , \quad (21)$$

and, to first order in  $f$ ,

$$f = \frac{(13/\text{sec})_c}{(13/\text{sec})_M} = \frac{(13/\text{sec})_c}{(13/\text{sec})_s} . \quad (22)$$

The second equality is true when the sample,  $S$ , has the same graphite mass as the matrix,  $M$ , used to determine  $f$ . Using Eq (22), the ratio  $\frac{(14/\text{sec})_c}{(14/\text{sec})_s}$  in Eq (20) can be written

$$\frac{(14/\text{sec})_c}{(14/\text{sec})_s} = \frac{(14/\text{sec})_c / (13/\text{sec})_s}{(14/13)_s} = \frac{f (14/13)_c}{(14/13)_s} = \frac{f (14/13)_{1950}}{(14/13)_s} , \quad (23)$$

so that Eq (20) can be rewritten as

$$(14/13)_S = (14/13)_m (1 + f) - f (14/13)_{1950} . \quad (24)$$

The fraction of modern of the sample,  $F$ , in terms of the fraction of modern, measured,  $F_m$ , is obtained by dividing both sides of Eq (24) by  $(14/13)_{1950}$ . Since we have assumed that the contamination material is modern, no blank correction is necessary to the measured ratio,  $(14/13)_{1950}$ , and

$$F = F_m (1 + f) - f , \quad (25)$$

where

$$F_m = \frac{(14/13)_m}{(14/13)_{1950}} .$$

In a slightly different form,

$$F = F_m \left[ 1 - f \left\{ \frac{1}{F_m} - 1 \right\} \right] , \quad (26)$$

and the term in square brackets is the blank correction factor, (BCF).

For a modern (1950) sample,  $F_m = 1$ , and the blank correction factor is unity. For a one-milligram sample with  $F_m = 0.7$ , corresponding to a radiocarbon age of ca 3000 BP,  $f = 0.004 \pm 0.001$ , and the correction factor is

$$\text{BCF} = 0.9983 \pm 0.0004 .$$

The range from 3000 BP to modern covers those ages for which the highest precision is usually desired. As can be seen, for one-milligram samples, background corrections in this range contribute  $< 0.1\%$  (1‰) to uncertainties. However, for a 100-microgram sample with  $F_m = 0.7$ , the  $\text{BCF} = 0.983 \pm 0.005$ .

Finally, in the limit as  $1/F_m \gg 1$  ( $F_m \leq 0.1$ ; radiocarbon age  $\geq 20,000$  BP), Eq (26) can be written

$$F = F_m - f . \quad (27)$$

The minimum value of  $F$  that can be measured is defined as

$$F = F_m - f \geq 2\Delta f .$$

For a one-milligram sample, where  $\Delta f = 0.001$ , this limit corresponds to a maximum age of 49,900 years. For a sample with a mass of 100 micrograms, the maximum age that can be measured at present with our instrument is ca 30,000 years.

## ACKNOWLEDGMENTS

The section on Isotope-Ratio Calculations, above, was formulated in its entirety from notes of TW Linick, who was certainly one of the world's experts in radiocarbon measurements. His expertise and his gentle personality are sorely missed in this laboratory. This work was supported in part by NSF grant EAR 8822292.

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## APPENDIX

If, instead of assuming that  $(14/13)_c = (14/13)_{1950}$ , we use  $(14/13)_c = g (14/13)_{1950}$ , then Eq (24) becomes

$$(14/13)_s = (14/13)_m (1 + f/g) - f (14/13)_{1950} , \quad (\text{A1})$$

and

$$(14/13)_{1950} = \left\{ (14/13)_{1950} \right\}_{\text{measured}} \left( \frac{1 + f/g}{1 + f} \right) , \quad (\text{A2})$$

so that Eq (26) becomes

$$F = F_m \frac{(1 + f/g - f/F_m)}{\frac{1 + f/g}{1 + f}} . \quad (\text{A3})$$

If  $f/g \ll 1$ , then, to first order in  $f$  and  $f/g$ , Eq (A3) can be written

$$F = F_m (1 + f - f/F_m) \quad (\text{A4})$$

which is identical with Eq (25). Thus, if  $f = 0.004$ , Eq (6) is correct for  $g \geq 0.04$ , or  $(14/13)_c \geq 0.04 (14/13)_{1950}$ .

## MARINE TURTLE BONES FROM AN ARCHAEOLOGICAL SITE IN POLYNESIA YIELD RELIABLE AGE DETERMINATIONS

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**ABSTRACT.** Accelerator mass spectrometry dating of three 50g samples of marine turtle bone from the basal cultural stratum of the Tongoleleka archaeological site, Lifuka Island, Kingdom of Tonga, South Pacific yields results that agree with conventional  $^{14}\text{C}$  dates on marine shell. A method for calibrating these dates that takes into account the long distance migrations of marine turtles in the South Pacific is proposed. A sample size greater than 50g is recommended for routine AMS dating of marine turtle bone.

Wood charcoal samples of sufficient size for routine radiocarbon dating are rare in the oldest cultural layers of most archaeological sites in Polynesia. Routine accelerator mass spectrometry (AMS) dating of bone proteins gives archaeologists an important new source of datable materials (James *et al* 1987; Gillespie, Hedges & Humm 1986; Stafford *et al*, in press), since many early Polynesian sites contain abundant bones of animals eaten by colonists (Dye & Steadman, in press). This paper describes the results of AMS dating of marine turtle bones from an early archaeological site in the Kingdom of Tonga. It also provides data on the minimum sample size for routine AMS dating of marine turtle bone samples and proposes a procedure for calibrating age estimates from marine turtle bone collected at archaeological sites in the South Pacific.

Marine turtle bones were collected from the basal cultural stratum of the Tongoleleka site on Lifuka Island (19°49'S, 174°25'W) in the Ha'apai Group, Kingdom of Tonga. The basal cultural stratum of the Tongoleleka site represents the initial occupation of a sand dune located along a prograding shoreline by a people who manufactured a distinctive dentate-stamped earthenware (Dye 1988). On stylistic and technologic grounds, this earthenware can be classified as Early Eastern Lapita pottery (Green 1979), which differs from succeeding pottery styles by the large areas of the pot that were decorated, the complexity of the dentate-stamped decoration, and the diverse vessel forms that were produced. Previous studies indicate that the makers of Early Eastern Lapita pottery were the initial settlers of Tonga (see Bellwood 1979; Davidson 1979; Kirch 1984). A recent evaluation of the settlement period  $^{14}\text{C}$  age estimates concludes that the Lapita potters settled the Tongan Islands in the 9th century BC (Poulsen 1987). The age of the Tongoleleka site is of further interest because the bones of five species of extinct birds (Steadman 1989) and an extinct iguana (Pregill & Dye 1989) were recovered from the basal cultural stratum there.

The three 50g samples reported here (AA-1920, -1921, -1923) each represent the postcranial remains of one or more individuals of one or more unidentified marine turtle genera. Based on modern estimates of marine turtle population sizes in Tonga (Pritchard 1982), the bones are most likely those of the green turtle (*Chelonia mydas*) or the hawksbill turtle (*Eretmochelys imbricata*). The samples were selected from stratigraphically secure contexts associated with Early Eastern Lapita pottery, other artifacts and abundant food remains, including the bones of extinct birds and iguanas. A marine turtle bone concentration index of 414g/m<sup>3</sup> of excavated deposit in the basal cultural stratum of the Tongoleleka site contrasts strongly with the lack of marine turtle bone in the underlying, presettlement stratum. It is unlikely that the bones derived from some older, natural deposit. Similarly, a decline in the amount of marine turtle bone in the middle strata (22-146g/m<sup>3</sup>) and upper stratum (17g/m<sup>3</sup>) of the site diminishes the possibility that the analyzed bones were introduced into the basal cultural stratum from younger cultural deposits. There is thus every indication that the analyzed marine turtle bones are contemporaneous with the cultural materials in the basal cultural stratum of the site.

$^{14}\text{C}$  measurements were made by the NSF-Arizona Accelerator Facility for Radioisotope Analysis, following procedures described by Gillespie, Hedges & Humm (1986) for preparation of the bone samples. Sample AA-1920 yielded insufficient carbon for routine analysis and was diluted 2:1 with  $^{12}\text{CO}_2$ . A fourth sample (AA-1922) yielded only 0.044% N and could not be analyzed. Thus, samples larger than 50g are recommended for routine AMS dating of marine turtle bone from early Polynesian archaeological sites.

The choice of a calibration curve is dictated by the diets of marine turtles. The omnivorous diets of both green (mainly herbivorous) and hawksbill turtles are dominated by plants and animals found in shallow water marine ecosystems (Mortimer 1982; Bjorndal 1985). Studies of stable carbon isotopes in these ecosystems indicate that the primary source of organic carbon is the reef benthos, and that detritus derived from land contributes a negligible amount of carbon (Smith, Schneider & Tribble 1985). The  $\delta^{13}\text{C}$  values of  $-17.9$  for samples AA-1921 and -1923 fall at the light end of the range of  $\delta^{13}\text{C}$  values determined from sediments derived from coral reefs and sea grasses, but are heavier than sediments with a terrigenous component (Smith, Schneider & Tribble 1985: 446). The  $\delta^{13}\text{C}$  value for sample AA-1920 was not estimated in the laboratory, but is assumed to be the same as the other two samples. Thus, with the aid of the computer program CALIB (Stuiver & Reimer 1986), the age estimates were calibrated using the marine model of Stuiver, Pearson & Braziunas (1986).

The geographic range of marine turtle migrations complicates the selection of an appropriate correction factor ( $\Delta R$ ) for the marine model. Tag and recapture studies indicate that individual green turtles in the South Pacific range over 4500km from the Society Islands to Vanuatu (Meylan 1982). Less is known of the range of hawksbill turtles, although evidence suggests that they migrate long distances as well (Meylan 1982: 96). Green turtles in the South Pacific appear to be isolated from populations in the North Pacific (Balazs 1982). These long distance migrations mean that marine turtles ingest carbon from a wide range of local marine environments in the South Pacific, each of which is likely to differ in its own way from the marine model of Stuiver, Pearson & Braziunas (1986). To date, a single  $\Delta R$  estimate from a South Pacific island group in the green turtle's range,  $45 \pm 30$  from the Society Islands (Stuiver, Pearson & Braziunas 1986), is available, and this has been applied. As more  $\Delta R$  estimates for the South Pacific become available, an average of these values would perhaps more closely model the carbon intake of marine turtles.

The reliability of age estimates from marine turtle bone may be assessed by comparing them with age estimates from other materials associated with Early Eastern Lapita pottery. Two stratigraphically secure samples of marine shells (ANU-541 and NZ-727) from Tongatapu (Poulsen 1987: Table 32), the nearest island with comparable dated cultural remains, provide the best basis for comparison. According to Poulsen's (1987: 78-80) detailed stratigraphic analyses, these are the only  $^{14}\text{C}$  samples from Tongatapu that can be confidently associated with dentate-stamped pottery similar to that recovered from the basal stratum of the Tongoleleka site. Figure 1 compares the  $1\sigma$  and  $2\sigma$  age ranges of the Tongoleleka marine turtle samples with age estimates from the two Tongatapu marine shell samples. Samples AA-1921 and -1923 fit well with the Tongatapu age estimates, overlapping at  $1\sigma$ . Sample AA-1920, which was diluted with  $^{12}\text{CO}_2$ , appears to be older than the other samples.

Two hypotheses could explain the discrepancy between the age of sample AA-1920 and the other two turtle bone samples. The first is that the age estimate for sample AA-1920 is a statistical outlier, and that the actual age of the sample is younger than the estimate by ca  $3\sigma$ . The second is that sample AA-1920 actually dates an early portion of the Lapita period in the region, and that the three turtle bone samples together accurately estimate the duration of the Early Eastern Lapita period in Tonga. This second hypothesis receives apparent support from one  $^{14}\text{C}$  date (NZ-726)

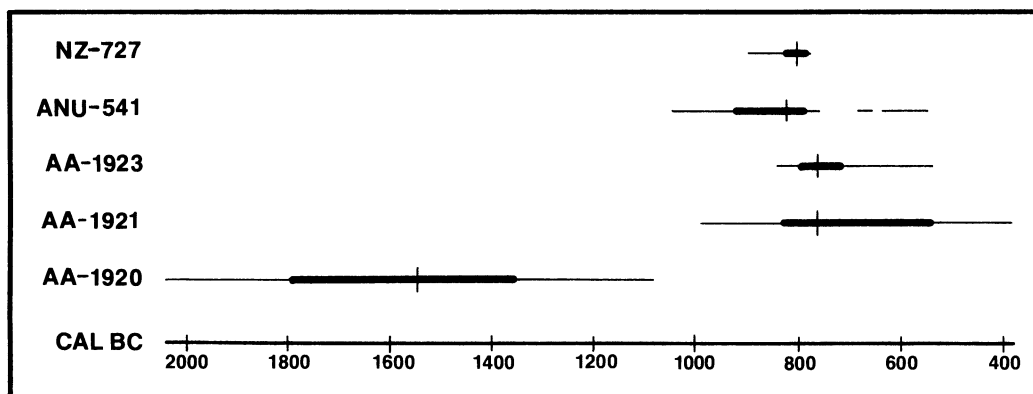


Fig 1. Calibrated age ranges ( $\blacksquare$  =  $1\sigma$ ;  $\text{---}$  =  $2\sigma$ ) and intercepts ( $|$ ) of marine turtle bone samples from Tongoleleka compared with calibrated age ranges ( $1$  &  $2\sigma$ ) and intercepts of marine shell samples (ANU-541, NZ-727) from Lapita period archaeological sites on Tongatapu Island, Kingdom of Tonga (Poulsen 1987: Table 32). The Tongoleleka samples are corrected with the calibration curve of Stuiver, Pearson & Braziunas (1986). The Tongatapu shell samples, corrected for oceanic reservoir effect by Polach (1987), are calibrated with the curve of Pearson and Stuiver (1986). Note that samples AA-1921 and -1923 overlap the two marine shell samples at  $1\sigma$ .

from Tongatapu with a calibrated  $1\sigma$  age range of 1495-1370 BC (Poulsen 1987, Table 32) and two (I-10632 and -10633) from Niuatoputapu, a small island at the northern end of Tonga (Kirch 1988: 140). The two Niuatoputapu samples yielded calibrated  $1\sigma$  age ranges of 1735-1508 BC and 1530-1373 BC, respectively. There are reasons to question whether these three samples actually date Early Eastern Lapita culture in Tonga, however. NZ-726 was recovered in a disturbed context and has not been accepted by prehistorians (Groube 1971: 302; Green 1979: 33; Kirch 1984: 50; Poulsen 1987: 79). Both of the Niuatoputapu samples are from giant clam (*Tridacna* sp) shells that were presumably taken from the lagoon where groundwater discharge through the uplifted limestones and unconsolidated calcareous sands adjacent to the lagoon (Kirch 1988: 21-23) may have introduced significant amounts of old carbon into the marine environment. Two charcoal samples from the same stratum of site NT-90 (Kirch 1988: 140) yielded corrected  $2\sigma$  age ranges of 155 BC-AD 460 (I-9934) and AD 650-1135 (I-10481), both significantly younger than the *Tridacna* shell samples. Thus, there is insufficient evidence with which to discriminate between the two hypotheses. The duration of the Lapita period in Tonga will be reliably estimated, and anomalous dates identified, only after additional stratigraphically secure samples from the region are collected and dated. Ottaway (1973) describes a suitable technique for estimating the duration of cultural periods with  $^{14}\text{C}$  dates.

AMS dating of ca 2800-yr-old marine turtle bones from a Lapita period archaeological site yields results that agree with conventional  $^{14}\text{C}$  ages from marine shells recovered from similar cultural contexts. The suggestion that marine turtle bone is a suitable material for AMS dating will be strengthened if comparable ages can be obtained from stratigraphically associated marine turtle bone and marine shell or charcoal from the same site.

## ARCHAEOLOGIC SAMPLES

## Lifuka Island series

- 3660 ± 190**  
*Est*  $\delta^{13}C = -17.9\%$
- AA-1920. Lifuka Island**
- Marine turtle bone from Tongoleleka site, Unit 0N0W, Layer IV; assoc with Lapita pottery and bones of extinct birds and iguanas. *Comment:* cal 1790 (1543) 1360 BC at 1 $\sigma$ ; cal 3739 (3492) 3309 BP at 1 $\sigma$ .
- 2960 ± 120**  
 $\delta^{13}C = -17.9\%$
- AA-1921. Lifuka Island**
- Marine turtle bone from Tongoleleka site, Unit 45N1W, Layer IV; assoc with Lapita pottery and bones of extinct birds and iguanas. *Comment:* cal 830 (763) 540 BC at 1 $\sigma$ ; cal 2779 (2712) 2489 BP at 1 $\sigma$ .
- 2960 ± 60**  
 $\delta^{13}C = -17.9\%$
- AA-1923. Lifuka Island**
- Marine turtle bone from Tongoleleka site, Unit 0N0W, Layer IV; assoc with Lapita pottery and bones of extinct birds and iguanas. *Comment:* cal 797 (763) 720 BC at 1 $\sigma$ ; cal 2746 (2712) 2669 BP at 1 $\sigma$ .

## ACKNOWLEDGMENTS

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## RADIOCARBON DATING OF THE NEOLITHIC EARLY BRONZE AGE SITE OF MANDALO, W MACEDONIA

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### INTRODUCTION

The following list of dates was obtained in a joint German-Greek project to establish a radiocarbon dating laboratory in the National Research Centre for Physical Sciences "Demokritos," Athens, Greece.<sup>1</sup> Although our initial aim in selecting these samples was to study laboratory procedures, we found that when the dates were arranged in stratigraphic order they provided a chronological framework for Thessalian and northern Macedonian site of the Late Neolithic and Early Bronze Ages (Kotsakis *et al* 1989; Papanthimou & Papasteriou 1987a).

The dates were obtained by CO<sub>2</sub> gas counting in the Heidelberg laboratory (Schoch *et al* 1980). Dates are expressed as radiocarbon years relative to 1950 (Stuiver & Polach 1977) and are corrected for isotopic fractionation. Errors quoted are based on counting statistics of sample, background and standard (SRM 4990) and expressed as 1 standard deviation ( $\sigma$ ).

All samples listed here come from the prehistoric site of Mandalo in Western Macedonia, (40°52'N, 22°13'E) 65km northwest of Thessaloniki. The site is being excavated by archaeologists A Pilali-Pasteriou, A Papanthimou-Papaefthimiou and K Kotsakis of the University of Thessaloniki and T Savopoulou of the Archaeological Museum of Thessaloniki. The samples were all charcoal and were submitted by the excavators (Papasteriou *et al* 1983; Papanthimou & Papasteriou 1987b).

The site of Mandalo is approximately 20km west of the classical capital of Macedonia Pella. It is in the foothills of Mount Paikou in the lowland hills that separate the now dried Yannitsa Lake from Aridaia Plain. It is a small tell site that covers an area of not more than 0.2ha in its base, and has a height of 7m. The site can be divided into 4 occupational phases: Ia, Ib, II and III. Mandalo is perhaps the first prehistoric site in Greece that has been radiocarbon dated so consistently and systematically. It therefore provides a very significant chronological reference.

### ARCHAEOLOGICAL SAMPLES

**HD-9597.      D12      6630 ± 100**

Sample directly overlay sterile layer.

$\delta^{13}\text{C} = -24.8\text{‰}$

*Comment:* date is considered too early.

<sup>1</sup>The laboratory is now fully operational. It will use the code designation, DEM.

<b>HD-9601.</b>	<b>4007</b>	<b>5710 ± 150</b>
	Sample from destruction level, probably floor, Mandalo Phase Ib.	$\delta^{13}C = -22.0\text{‰}$
<b>HD-9562.</b>	<b>3120</b>	<b>5600 ± 70</b>
	Sample from earliest floor of last house in Mandalo Phase Ib.	$\delta^{13}C = -25.8\text{‰}$
<b>HD-9265.</b>	<b>4020</b>	<b>5540 ± 70</b>
	Sample from postholes of a house, Mandalo Phase Ib.	$\delta^{13}C = -24.1\text{‰}$
<b>HD-9557.</b>	<b>5032</b>	<b>5440 ± 60</b>
	Sample from destruction of the latest house of Mandalo Phase Ib.	$\delta^{13}C = -25.3\text{‰}$
<b>HD-9559.</b>	<b>2156</b>	<b>5490 ± 60</b>
	Sample from destruction layer of a pile house; underlain by baby burial in vase, Mandalo Phase II.	$\delta^{13}C = -24.7\text{‰}$
<b>HD-9563.</b>	<b>2202a</b>	<b>5430 ± 70</b>
	Sample from earliest part of Mandalo Phase II; corner of house built with wooden posts.	$\delta^{13}C = -24.0\text{‰}$
<b>HD-9939.</b>	<b>2202b</b>	<b>5430 ± 45</b>
	Second sample from same layer; dated to check consistency.	$\delta^{13}C = -24.3\text{‰}$
<b>HD-9595.</b>	<b>2224</b>	<b>6410 ± 190</b>
	Sample from interior of house.	$\delta^{13}C = -24.7\text{‰}$
<b>HD-9602.</b>	<b>1022</b>	<b>5460 ± 100</b>
	Sample from destruction of Mandalo Phase II.	$\delta^{13}C = -25.2\text{‰}$
<b>HD-9596.</b>	<b>7229</b>	<b>5290 ± 70</b>
	Sample from same destruction level as 1022, west of stratigraphic section. Sample is associated with storage bin underlying destruction level.	$\delta^{13}C = -24.8\text{‰}$
<b>HD-9833.</b>	<b>7253</b>	<b>5460 ± 50</b>
	Sample from destruction level of house, Mandalo Phase II.	$\delta^{13}C = -24.8\text{‰}$
<b>HD-9834.</b>	<b>7275</b>	<b>5340 ± 100</b>
	Sample from yellow layer underlying destruction level, with remains of burned clay and small pieces of charcoal, Phase II.	$\delta^{13}C = -25.9\text{‰}$

<b>HD-9835.</b>	<b>8152</b>	<b>4300 ± 100</b> $\delta^{13}C = -26.0\text{‰}$
Sample from layer directly overlying destruction level of Phase II (EBA).		
<b>HD-9915.</b>	<b>8231</b>	<b>4130 ± 40</b> $\delta^{13}C = -25.3\text{‰}$
Sample from destruction level of house, Phase III.		
<b>HD-9216.</b>	<b>7140</b>	<b>4130 ± 70</b> $\delta^{13}C = -25.7\text{‰}$
Same as HD-9835.		
<b>HD-9907.</b>	<b>8119</b>	<b>3920 ± 40</b> $\delta^{13}C = -25.1\text{‰}$
Sample from pits that were possibly cut from near surface (EBA).		
<b>HD-9146.</b>	<b>1024</b>	<b>3860 ± 70</b> $\delta^{13}C = -25.2\text{‰}$
Same as above.		
<b>HD-9603.</b>	<b>3040</b>	<b>5520 ± 80</b> $\delta^{13}C = -24.8\text{‰}$
Sample from postholes of wall, Phase Ib.		
<b>HD-9832.</b>	<b>7251</b>	<b>5420 ± 40</b> $\delta^{13}C = -24.5\text{‰}$
Same as HD-9833, above.		

*General Comment:* Figure 1 shows the calibrated dates placed in their stratigraphic order. The data were calibrated using the computer program supplied by Stuiver and Reimer (1986). The calibration is based on Stuiver and Pearson (1986), Pearson and Stuiver (1986), Pearson *et al* (1986), Linick, Suess and Becker (1985), Stuiver *et al* (1986), Kromer *et al* (1986) and Linick *et al* (1986). The age ranges in the figure are represented by bars where the length represents the age range and the height represents the percent probability that the sample is in the specific range.

It is obvious that the dates form two well-defined groups. Phases Ib and II are clearly dated to the 5th millennium BC whereas Phase III dates to the 3rd millennium. There are no <sup>14</sup>C determinations from the 4th millennium. According to archaeological interpretation (Kotsakis *et al* 1989; Papanthimou & Papasteriou 1987a) there is no apparent discontinuity in the sampling along the stratigraphic transition between Mandalo II and Mandalo III. Our results corroborate this finding and indicate that habitation was interrupted and resumed at the site after a long period had passed, perhaps as much as a millennium.

On the basis of typological similarities, Mandalo Ib and II can be associated with Malia II, Suplevac, Bakarno-Gumno I-II and Ernobuki I-II (Kotsakis *et al* 1989; Papanthimou & Papasteriou 1987a). There are no <sup>14</sup>C dates for these Albanian, south Yugoslavian sites. These groups are usually linked with the Rachmani culture of Thessaly.

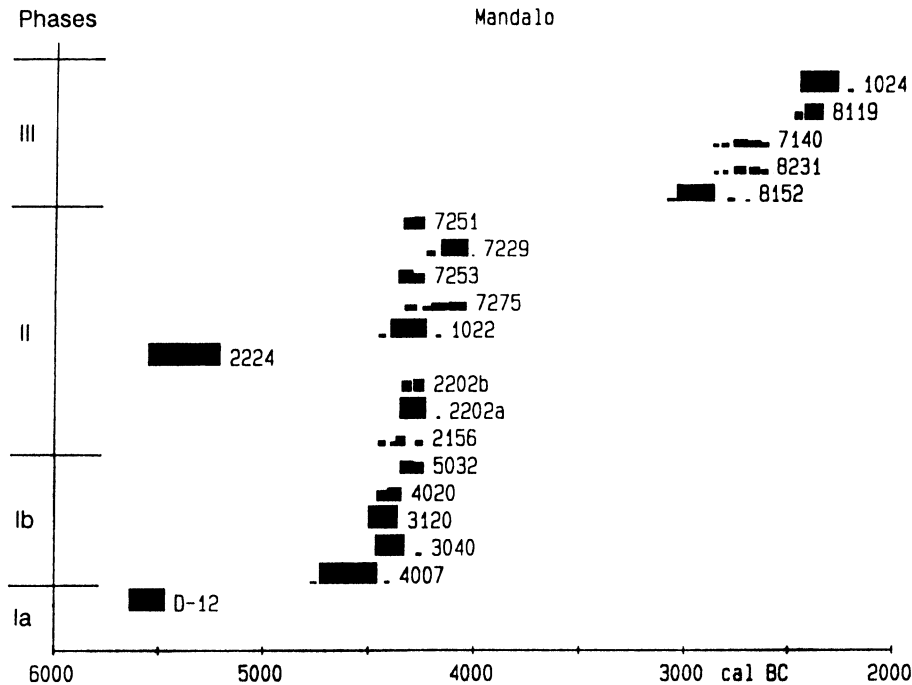


Fig 1. The distribution of dates for the Mandalo site, West Macedonia, Greece. The length of the bars represents the age range; the height represents the percent probability that the sample lies in the specific range.

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**PREPARATIVE HIGH-PERFORMANCE LIQUID CHROMATOGRAPHIC  
SEPARATION OF INDIVIDUAL AMINO ACIDS DERIVED FROM  
FOSSIL BONE COLLAGEN**

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**ABSTRACT.** Extracting a series of amino acids from fossil "collagen" makes it possible to compare chemically well-characterized molecules from one bone sample, both chemically and by isotopic analysis. Thus, the integrity of collagen samples and possible contamination can be checked. We describe the routine high-performance liquid chromatographic extraction of five amino acids: glycine, hydroxyproline, glutamate, threonine and alanine. Humates are eliminated during the extraction, which can be monitored continuously.

INTRODUCTION

Conventional methods of <sup>14</sup>C bone dating and paleodietary stable isotope research often lead to ambiguous results due to problems in extracting uncontaminated, unaltered bone collagen from degraded bone (eg, Longin 1971; Olsson *et al* 1974; El-Daoushy, Olsson & Oro 1978; Taylor 1980, 1987).

We do not fully understand the collagen degradation process during bone diagenesis (Schwarcz, Hedges & Ivanovich 1989; Stafford, Brendel & Duhamel 1988; Gillespie 1986; Hedges & Law 1989), and the changes in bones in the soil are as diverse as the specific circumstances to which they were exposed during their burial. Descriptions of collagen preservation are inadequate for describing alterations in a fossil bone "collagen" sample, at least at the molecular level.

Extracting collagen from fossil bone in the form of gelatin (denatured, unfolded collagen) is not a totally selective process (Gurfinkel 1987; Taylor 1980; Gillespie, 1986; Stafford, Brendel & Duhamel 1988). Isotope analysis of fossil bone gelatin depends on mass balance and isotopic differences between endogenous (and isotopically unchanged) collagenous material and other materials that attach to it during diagenesis. These materials (eg, humics) can be exogenous or formed *in situ* from collagen parts and may or may not be isotopically different from the original collagen fiber.

Thus, the state of preservation of fossil "collagen" is crucial for accuracy in the resulting isotopic analyses (Stafford, Brendel & Duhamel 1988). A better chemical characterization of the fraction selected for dating would be the first step in improving the validity of both bone dating and paleodietary analysis. This means using distinct molecules such as amino acids or specific proteins rather than insoluble residues. For radiocarbon dating, this possibility has come within reach since the development of accelerator mass spectrometric (AMS) <sup>14</sup>C detection. AMS requires a very small sample: milligram quantities instead of grams, required for conventional radiocarbon dating (Mook 1984). At present, some researchers prefer to extract larger or smaller (peptide) parts of collagen (Brown *et al* 1988; DeNiro & Weiner 1988a,b), or other bone proteins (Gillespie 1989). Others extract a mixture of amino acids from "collagen" (Ho, Marcus & Berger 1969; Stafford *et al* 1987; Hedges *et al* 1989), or one or two specific amino acids, eg, hydroxyproline and proline (Wand 1981; Stafford *et al* 1982;

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Gillespie & Hedges 1983; Gillespie, Hedges & Wand 1984), or a series of individual amino acids (Hare & Estep 1983; Macko *et al* 1983; van Klinken 1989).

We describe here routine extraction of five individual amino acids from collagen hydrolyzates (glycine (Gly), glutamate (Glu), hydroxyproline (Hyp), threonine (Thr) and alanine (Ala)) by means of high-performance liquid chromatography (HPLC).

#### AMINO ACIDS AND ISOTOPE CHEMISTRY

##### *Collagen Amino Acids*

Biochemically intact bone collagen contains 18 different amino acids (Table 1). Not all amino acids are of equal interest in an isotopic comparison, nor can they be isolated in an equally routine way with the described HPLC system; thus, we must select carefully amino acids for routine analysis.

TABLE 1  
The amino acid composition of undegraded collagen

Amino Acid	Abbr	Residues ‰
Hydroxyproline*	Hyp	101
Aspartate	Asp	51
Threonine***	Thr	18
Serine	Ser	35
Glutamate*	Glu	75
Proline	Pro	116
Glycine*	Gly	317
Alanine*	Ala	113
Valine**	Val	19
Methionine	Met	5
Isoleucine**	Ile	13
Leucine**	Leu	28
Tyrosine	Tyr	5
Phenylalanine**	Phe	18
Hydroxylysine	Hyl	5
Lysine**	Lys	24
Histidine**	His	5
Arginine	Arg	49

\* Amino acid selected for investigation

\*\* Essential amino acid

The amino acids Hyp and hydroxylysine (Hyl) are typical for collagen. Hyp and Hyl are not incorporated in the polypeptide chains of collagen by the usual mechanisms of protein synthesis. Some specific proline (Pro) and lysine (Lys) residues are hydroxylated *in situ* after they are already incorporated in the  $\alpha$ -chain, the building block of collagen fiber. Hyl is important because carbohydrate units, mostly a disaccharide of glucose and galactose, become attached to it during collagen synthesis (glycosylation). Hyp is indispensable for the stabilization of the collagen superhelix because it increases the stability of the molecule by hydrogen bonding (Ramachandran & Reddi 1976); insufficient hydroxylation of Pro in living

bone occurs during scurvy. In collagen, Hyp accounts for ca 10% of the amino-acid residues; otherwise it occurs only in very low amounts. Because of this high bone-specificity, Hyp was recognized as an ideal dating sample at an early stage in the development of AMS (Wand 1981).

Based on biosynthetic relationships, carbon and nitrogen isotopic ratios in Glu, Pro and Hyp, as well as in Lys and Hyl must be identical, on average. The isotopic comparison of these amino acids could provide a test for contamination of fossil collagens. Unfortunately, the Hyl content of collagen is very low: ca 5 residues per 1000, which makes routine preparative isolation difficult. Hyp and Glu can easily be isolated (Fig 1), but Pro requires an extra buffer in the HPLC separation (Table 2).

Many amino-acid transamination reactions (involving a transfer of nitrogen from one amino acid to another) are known in animal biosynthesis, which could bring about other possibilities for  $^{15}\text{N}/^{14}\text{N}$  ratio comparison of different amino acids. For example, nitrogen is transferred from Glu to almost any other L-amino acid. Most probably, these amino acids are all isotopically lighter in nitrogen than Glu because of isotope effects during transamination (Macko *et al* 1987). Glu is the most abundant amino acid in nature, and fossil bone Glu is likely to be contaminated very easily with exogenous Glu. For this reason, Glu seems to be an ideal amino acid to test overall bone contamination.

Glycine (Gly), the smallest amino acid, accounts for one-third of the residues in collagen. Serine (Ser) is the precursor of Gly. Gly can be separated easily; in the case of Ser, an extra extraction run of 45 min is needed at a higher column temperature. A collagen molecule is likely to be largely deteriorated if a severe contamination with exogenous Gly appears to exist, indicated by deviating Gly concentrations and stable isotopic ratios. Consequently, all other isotopic measurements should be treated with caution.

The amino acids mentioned so far are non-essential, *ie*, they can be synthesized by the animal itself; Thr is one of the essential amino acids (Table 1): it has to be taken up with food. Thus,  $^{13}\text{C}/^{12}\text{C}$  and  $^{14}\text{C}/^{12}\text{C}$  isotope ratios of Thr relate to those of dietary Thr. On the other hand,  $^{15}\text{N}/^{14}\text{N}$  values appear to be slightly lower than those of dietary Thr, perhaps because of a preferential incorporation of  $^{14}\text{N}$  containing Thr (Gaebler, Vitti & Vukmirovich 1966).

Gly concentrations are often low in fossil bone samples, along with higher concentrations of valine (Val), isoleucine (Ile), leucine (Leu) and phenylalanine (Phe), and probably of Thr and Ser (Dungworth *et al* 1974).

### *Amino-Acid Separations*

One aspect of modern chromatographic separations has been underestimated: the importance of detecting the molecules we want to extract and possible contaminants *during* the isolation process. On-line detection allows us to continuously monitor the quality of each separation, and register each deviation. This can be done with HPLC, which yields a high-resolution separation together with excellent reproducibility in a relatively short time (2 hr). A preparative (milligram-scale) system with a low  $^{14}\text{C}$  background is needed for use in natural abundance isotope chemistry, essentially without memory or isotopic fractionation effects.

Most of the chromatographic amino acid separation methods are designed for analytical (nanomole level) use: either ion-exchange analyzers (Moore & Stein 1951) or reversed phase systems (eg, Joseph & Marsden 1986) with organic buffer systems and post- or precolumn derivatization. These do not suit the specific demands of fossil bone isotopic analysis. Carbon contamination from the organic buffers and derivatization reagents is difficult to avoid. For instance, ninhydrin derivatization reagent turned out to be severely contaminated by  $^{14}\text{C}$  (up to

10 times the activity of recent natural carbon), possibly because of contact with labeling compounds during manufacturing. The main disadvantage, however, is the fact that non-aminated contamination cannot be detected if derivatization techniques are used. For these reasons, we used direct UV detection at 210nm.

Spectrophotometric detection is based on the measurement of the absorbance of monochromatic light by the sample in accordance with the Lambert-Beer law:

$$c = [\log I_0/I_1] / \epsilon \cdot L$$

where  $c$  = concentration of unknown solution;  $I_0$  = intensity of the incident light of the used wave length (*ie*, 210 nm);  $I_1$  = intensity of the transmitted light;  $\log I_0/I_1$  being the absorbance  $A$  (formerly called extinction  $E$  or optical density  $D$ );  $\epsilon$  = molar absorption coefficient (formerly the extinction coefficient), dependent on the type of solvent, wave length and temperature;  $L$  = path length of light through solvent.

Spectrophotometric detectors provide an output in absorbance units which is linearly related to sample concentration over a range of  $10^5$ .

Baseline separation of amino acid peaks is indispensable for avoiding partial mixing of fractions, especially if we inject large amounts of sample. In fact, complete separation is not obtainable for all "collagen" amino acids, due to the complexity of the amino acid / "humics" mixture; thus, some of the amino acids have to be omitted.

We built an HPLC system with an inorganic buffer system, a cation exchange (sulphonated resin) column, and direct UV detection at 210nm. We separated amino acids with one buffer solution during a run of 145 min at a maximum load of 100mg of hydrolyzate. We can extract aspartate (Asp) and Ser in a separate run using a higher column temperature. An optional buffer for the separation of Pro, Val, Leu, and histidine (His) is available. We also can isolate some humic fractions and unhydrolyzed parts of collagen chains (peptides) if they are present.

Normally, we then analyze amino acids for their stable isotope content ( $^{13}\text{C}/^{12}\text{C}$ ,  $^{15}\text{N}/^{14}\text{N}$ ) to determine the optimal amino acids for dating. The chosen amino acids finally can be  $^{14}\text{C}$  dated by means of AMS.

## MATERIALS AND METHODS

### *Sample Selection*

As discussed above, the state of collagen preservation determines the quality of isotope results (see also Stafford, Brendel & Duhamel 1988). The choice of bone or part thereof can be crucial. We prefer dense bones, such as the shafts of long bones, over more porous ones. We obtained especially good results from dental elements, even from tropical soils where bone withers quickly. Both bone and dentin contain the same type of collagen (Type I, Bornstein & Traub 1979); however, the initial collagen content is higher in dentin (30% compared to ca 15% in bone), and dentin is much denser than bone. We found no differences in isotope content between bone and teeth (van Klinken *et al*, ms).

### *Mechanical Cleaning of the Bone Sample*

At first, we remove the bone surface, or we saw out a dense, unexposed section of the inner part of the bone. The selected material is ground to 0.5-1.5mm particles in a ball or chopping mill, making sure that the bone powder does not overheat.

### *Demineralization*

We subsequently decalcify the bone powder in dilute hydrochloric acid (3% HCl in doubly distilled water) at 4°C, stirring, adding 10ml aliquots of dilute acid until degassing stops. During demineralization, some of the collagen fibers will hydrolyze and become soluble if the temperature is too high or demineralization time is too long (Longin 1971; Brown *et al* 1988), and are then lost for the following gelatinization step. Demineralization time must be optimized for these opposing reactions. Under the described circumstances, the demineralization process lasts for 4 - 10 hr. After repeated centrifugation and washing with distilled water, the residue is used for gelatinization. However, in the smallest samples, the residue may not contain enough gelatin, in which case, the use of supernatant "collagen," the dilute acid-soluble fraction, is sometimes necessary.

### *Gelatinization*

Collagen fibril structure is lost during prolonged heating at temperatures higher than 58°C, the denaturation temperature of collagen (Piez 1984). During gelatinization, collagen fibers are unfolded and become soluble, while impurities (humates or severely degraded collagen parts) remain in the residue and can be eliminated by centrifugation (Longin 1971). Although gelatin extraction is not as selective as it once was thought to be (Gurfinkel 1987; Stafford *et al* 1987), it is still useful for improving the purity of fossil "collagen." The residue from the demineralization is placed in a shaking incubator at 75°C and a pH of ca 3 for 0.5 to 2 hr in closed glass containers. The steady movement speeds up the gelatinization process and improves the yield. Minimizing gelatinization time, temperature and air contact during the process prevents caramelization of the gelatin's carbohydrates, which appears as an increasingly yellow solution, and which could make the gelatin less accessible to further amino-acid extraction. The supernatant, containing the gelatin, is then freeze dried.

### *Hydrolysis*

The gelatin is hydrolyzed in doubly distilled 6N HCl (Suprapur, Merck; 3ml per 100mg of gelatin) for 20 hr at 110°C in sealed ampules. A part of the gelatin (up to 25%) is not hydrolyzed and remains a brown, insoluble residue. Experiments with higher temperatures, stronger acid, lower gelatin concentration and longer hydrolysis times failed to give better amino acid yields. Perhaps it is the more degraded part of the gelatin that is not, or only partially, sensitive to hydrolysis. Based on the differences in stable isotopic ratios between this residue and the intact "collagen," Hare and Estep (1983) suggest that the residue is a diagenetic product from lipids or carbohydrates from the glycosylated residues of the collagen fiber.

After hydrolysis, the sample is evaporated to dryness in a desiccator; subsequently, the amino acid mixture is redissolved in doubly distilled water, in a maximum concentration of ca 100-120mg hydrolyzate per 1000 $\mu$ l. After centrifugation for 30 min at maximum speed, the hydrolyzate is ready for injection into the HPLC system.

### *Amino-Acid Separation*

The HPLC system is designed to handle samples in an automated or semi-automated way, in amounts sufficient for stable isotope analysis or radiocarbon dating (80-100mg of hydrolyzate). The system comprises a HPLC pump, a dead-volume injector with

interchangeable sample loops, a chromatographic column with waterbath heating, a variable wavelength UV detector, and a fraction collector, which also controls the stepwise gradient. The extraction system is kept in an overpressure dust-free room. The (semi-) preparative HPLC pump must be able to deliver buffer flows of at least  $20\text{ml}\cdot\text{min}^{-1}$ ; the stainless steel connecting tubing is 0.16cm OD, 0.051cm ID ( $1/16''\times 0.020''$ ). The preparative 22 x 500mm column contains sulphonated cation exchange resin, Alltech Rogel-S ( $10\mu\text{m}$  particle size). The column is heated by a waterbath/circulation system with a tolerance of  $0.5^\circ\text{C}$ . Coiled nickel tubing, 40cm long, is placed in front of the column to improve heat transfer to the solution. Directly after the column, the solution is water-cooled to  $30^\circ\text{C}$  using another 40cm piece of coiled nickel tubing. Normally, the injection valve is fitted with a  $1000\mu\text{l}$  sample loop, and is thoroughly cleansed with a detergent solution and doubly distilled water before each injection to prevent cross-contamination. We used a LKB 2151 variable wavelength UV-Vis detector at 210nm, fitted with a preparative flow-cell. A Gilson 201 fraction collector is used to collect fractions automatically (with peak/baseline detection) or manually, and to control the buffer change-over valves. Chemicals are pa grade; the de-ionized water is filtered and de-aerated in a vacuum filter system (filters  $0.45\mu\text{m}$ , Millipore); and buffer solutions are continuously flushed with helium.

The separation of the amino acid peaks is optimized using Sigma L-amino-acid probes until retention time and peak shape of each amino acid give a baseline separation at preparative loads and at 0.04 AUFS (Absorbance Units Full Scale) of the UV detector sensitivity. We checked amino acid purity by classical amino analysis: purity of amino acid fractions, isolated under the described elution conditions did not differ from the pa Sigma amino acids (for a summary of the elution conditions, see Table 2). We quantify the content of each amino acid in a sample using Sigma Collagen Standard mixture.

The entire amino acid elution sequence is different from the classical sequence of amino-acid analyzers, but we have found no explanation for this phenomenon.

TABLE 2  
Elution conditions during preparative separations

Buffer flow rate	$18.01\cdot\text{min}^{-1}$
Pressure	36 bar (at $74.5^\circ\text{C}$ )
Column	22mm x 500mm Rogel-S, Alltech $10\mu\text{m}$ particle size, 10nm pore size Temperature $74.5^\circ\text{C}$ (increased to $80^\circ\text{C}$ for Asp and Ser separation)
Detector	UV detection at 210 nm (Semi-) preparative flowcell 0.04 or 0.08 AUFS (preparative load of 50-100mg collagen hydrolyzate)
Buffer system	A $0.1\text{M NaH}_2\text{PO}_4 + 0.1\text{M H}_3\text{PO}_4$ pH = 2.12 ( $25^\circ\text{C}$ ) B idem; pH = 4.50 optional C $.04\text{M NaOH}$ cleaning and column regeneration
Gradient	Stepwise; duration from moment of injection: A 100 min; (B 30 min); C 15 min; A 30 min

Isotope fractionation occurs during the chromatographic separation; we have observed  $\delta^{13}\text{C}$  differences of maximally 50‰ between the first and the last parts of a Gly peak (*cf* Macko *et al* 1987). To overcome this effect, we collected complete baseline separated peaks with small baseline parts before and after the peak. The resulting average variation in Gly, the smallest amino acid, and consequently the most susceptible to isotopic fractionation (Macko *et al* 1987), is  $\pm 0.5\text{‰}$  for  $\delta^{15}\text{N}$  and  $\pm 0.4\text{‰}$  for  $\delta^{13}\text{C}$ .

The  $^{14}\text{C}$  background is presently found to be lower than corresponding to 37,000 BP, with >50,000 BP collagen as a testing material.

### Desalting

The buffer phosphate salts in the collected HPLC fractions destabilize the combustion for isotope analysis by creating a fluctuating carbon background in the oxygen flow combustion system. Therefore, the amino acids are desalted by elution of the fractions over a 1.8 x 40cm column of AG 11 A8 (Biorad), at a flowrate of  $1\text{ml}\cdot\text{min}^{-1}$ . The salt-free amino-acid solution is then lyophilized.

Recently, we found buffer salts to give less problems using a  $\text{Cr}_2\text{O}_3$  combustion system (CHN analyzer), so we can omit desalting procedures in many of these combustions.

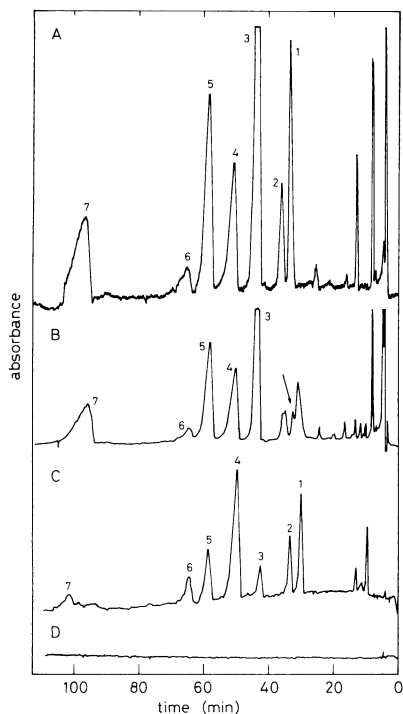


Fig 1A. A preparative separation (run #478) of a fossil "collagen" CI ( $^{14}\text{C}$  age 1700 BP), detector 0.08 AUFS. B. Preparative separation (run #493) of "collagen" Malmok 15, Asp and Ser are deformed (arrow), detector 0.08 AUFS. C. Analytical run (#494) of Sigma Collagen Standard, undiluted,  $2.5\mu\text{mol}$  of each amino acid, except  $12.5\mu\text{mol}$  Hyp, detector 0.02 AUFS. D. Blank run (#453), 0.08 AUFS. Other elution conditions as described in Table 2. L-Amino acids: 1 Asp, 2 Ser, 3 Gly, 4 Hyp, 5 Glu, 6 Thr, 7 Ala.

## RESULTS AND DISCUSSION

Figure 1 shows examples of HPLC separation chromatograms. In Figure 1A, a chromatogram of a preparative extraction of a "collagen" sample with an age of 1700 BP shows baseline separation of the five amino acids Gly, Hyp, Glu, Thr and Ala. Asp and Ser are not

fully separated and thus cannot be used for isotopic analysis. Peaks during the first 30 min represent salts and humic fractions. Figure 1B shows irregularities in the shape of the Asp and Ser peaks, so that these amino acids should be treated with caution. Figure 1C is an analytical chromatogram of the reference material, Sigma Collagen Standard. Figure 1D shows a blank run.

Routine separation of individual amino acids from fossil bone removes all soil contaminants (eg, humates; Stafford, Brendel & Duhamel 1988), except soil amino acids that have become attached to the bone collagen *in situ* during diagenesis. Free amino acids from the soil are washed out during gelatin preparation steps. Chemical bonding of exogenous amino acids can result in 1) a changed amino-acid composition (collagen differs considerably from the average protein), which can be detected during the HPLC separation, 2) in deviating stable isotope values of contaminated amino acids, which uncontaminated have characteristic isotopic compositions (Hare & Estep 1983), or 3) in different  $^{14}\text{C}$  ages of amino-acid fractions. These possibilities for identification of suspected samples will increase the quality of  $^{14}\text{C}$  bone dating. However, wherever possible,  $^{14}\text{C}$  dating of Hyp fractions should be preferred, because only Hyp is bone-specific to a high degree. All other amino acids occur in soils as well, and the sensitivity of chemical and stable isotope analysis is not sufficient to ensure correct  $^{14}\text{C}$  ages. Therefore, individual  $^{14}\text{C}$  measurements should be performed on these amino acids to distinguish between contaminated and uncontaminated fractions.

Macko *et al* (1983) separated individual amino acids using classic ion-exchange chromatography; unfortunately, they do not give many details of separation conditions. Hare & Estep (1983) were the first to report isotope composition of collagen amino acids using this extraction system. The use of HCl as a volatile eluent facilitates collection of salt-free amino acids. It is not easy to use HCl in HPLC, so we choose a phosphate buffer system. Because these buffers are non-volatile, we needed to desalt fractions prior to combustion, introducing another step. However, as we found out later, desalting is not strictly necessary when using a CHN analyzer to combust samples.

The advantages of HPLC techniques over low-pressure chromatography are better separation, high reproducibility of retention times and thus direct identification of peaks, constant monitoring, and much shorter extraction times.

Theoretically, bone contamination during diagenesis can be eliminated as a source of erroneous bone datings by extracting and comparing individual amino acids. Only laboratory procedures, consisting of controllable factors, in principle, determine sample contamination.

The approach described here enables us to use chemically well-defined sample materials, *ie*, amino acids, instead of more uncontrollable collagen extracts. The same results may be obtained by the possible extraction of well-preserved (hydrophobic) proteins (Gillespie 1989). The comparison of different amino acids from one bone sample presents new opportunities in the evaluation of bone radiocarbon ages and stable isotope data for paleodietary reconstruction or for the study of isotope fractionation effects in biosynthetic processes.

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## HARWELL RADIOCARBON MEASUREMENTS VIII

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### INTRODUCTION

Following Harwell Measurements VI (Walker & Otlet 1988) this is the second of the series of lists of English archaeological dates commissioned for measurement by the Historic Buildings and Monuments Commission for England and Wales within prescribed contractual periods. This list, containing 176 dates, refers to the period, April 1986 to March 1987, and results are reported irrespective of whether the associated projects are completed or ongoing.

Measurement procedures were essentially as reported earlier, with all three measuring systems of the Isotope Measurements laboratory having been used as appropriate to the sample size and requirements for measurement precision - standard liquid scintillation counting (Otlet & Warchal 1978) to a precision of  $\pm 1\%$ , miniature gas proportional counting (Otlet *et al* 1983; Otlet, Huxtable & Sanderson 1986) for the smaller samples and the higher precision ( $\pm 0.5\%$ ) liquid scintillation counting system brought into operation in 1985. In all cases, the error term quoted is the  $1\sigma$  standard deviation estimate of the full replicate sample reproducibility (Otlet 1979). Following further software developments, the basic text of the reports is now routinely prepared from database entries using an in-house microcomputer. National Grid References are abbreviated to NGR.

Calculations are based on the Libby half-life of 5568 years, using NBS oxalic acid standard (x0.95) as 'modern', both values treated as constants with AD 1950 as the reference year. All results are adjusted for fractionation according to the quoted  $\delta^{13}\text{C}$  (wrt PDB) values measured in the laboratory.

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### ARCHAEOLOGIC SAMPLES

**HAR-1313. SCILLY01** **2260  $\pm$  90**  
 $\delta^{13}\text{C} = -24.1\%$

Charcoal, with soil, AML 753220, from possible entrance to stone-built hut exposed in the seacliff and beneath a fossil sand dune at Halangy Porth, St Mary's, Isles of Scilly. Coll March and subm May 1975 by P Ashbee.

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**Milton Keynes series****HAR-854. MK223K-1**

**2460 ± 90**  
 $\delta^{13}C = -27.5\%$

Charcoal, AML 748093, from large Iron Age pit in which both artifactual and organic remains were preserved at Hartigan's Gravel Pit, Site MK 223, Milton Keynes. Coll Aug 1974 by T Schadla-Hall and subm Sept 1974 by H S Green, Natl Mus of Wales.

*Comment* (HSG): pit contained large and extremely important assemblage of decorated pottery including a Hunsbury bowl. This ceramic assemblage is of key importance in dating Iron Age pottery traditions.

**Beeston Castle series**

Three charcoal and one soil sample from Beeston Castle, Bunbury, Cheshire (53°7'43"N, 2°41'26" W, NGR SJ538593).

**HAR-4402. BCOGRC03**

**2380 ± 100**  
 $\delta^{13}C = -28.0\%$

Charcoal from fill of cylindrical posthole at top of ditch of outer ward. The posthole is 1 of 3 forming part of a tentative palisade with ambiguous relationship with supposed bank deposit. Coll Aug and subm Oct 1980 by P Hough.

**HAR-5610. BCOGRC07**

**1890 ± 120**  
 $\delta^{13}C = -26.4\%$

Charcoal from context BCO375A, timber *in situ* in stone rampart below foundation level of Medieval castle. Subm June 1983 by P H.

**HAR-6465. BC0624AA**

**2430 ± 70**  
 $\delta^{13}C = -25.0\%$

Charcoal, identified as *Fraxinus* sp, ash, AML 834980. Subm Aug 1984 by P H.

**HAR-8101. BEEBAH**

**1230 ± 90**  
 $\delta^{13}C = -27.9\%$

Soil, AML 841464, from humic A horizon, formed *in situ*. Coll Oct 1983 and subm Nov 1984 by R I McPhail, Inst Archaeol, London.

*Comment* (IMcP): Pollen profile taken through bank and ditch fill which include stable phase leading to organic matter deposition and old landsurface phase. Sample dates standstill phase in pollen sequence.

**Hambledon Hill series**

Charcoal samples from Hambledon Hill (Stepleton site), Iwerne Courtney, Blandford, Dorset (NGR ST847121). Coll and subm by R J Mercer, Univ Edinburgh.

**HAR-6038. HN82C13** **4530 ± 110**  
 $\delta^{13}C = -25.7\%$

From Ditch 3, Unit 6, Layer 5c, burned layer in butt end overlying natural chalk. Coll Sept 1982 and subm Nov 1983 by R J M.

*Comment* (RJM): suggests contemporaneity of whole ditch system tested so far.

**HAR-4438. ST8080** **4770 ± 80**  
 $\delta^{13}C = -25.3\%$

Identified as *Quercus* sp, from Feature no. 601. Subm Jan 1981 by RJM.

*Comment* (RJM): large timber *in situ* in gateway, apparently heartwood, relating to date of rampart construction.

#### Ribchester series

Charcoal from Ribchester, Lancashire. Coll and subm by A C H Olivier, Univ Lancaster.

**HAR-4445. RB80-057** **2860 ± 90**  
 $\delta^{13}C = -27.5\%$

Identified as hazel/alder (*Corylus/Alnus* sp) from mature timbers. Subm Feb 1981.

**HAR-4446. RB80068B** **3820 ± 120**  
 $\delta^{13}C = -26.9\%$

Identified as oak (*Quercus* sp) from secondary vessel; fill from internal vessel.

#### Mingie's Ditch series

Samples from Mingie's Ditch, floodplain of River Windrush, Hardwick-with-Yelford, Oxon (51°45'0" N, 1°26'1" W, NGR SP391059). Coll and subm by M A Robinson, Univ Museum, Oxford.

**HAR-8354. HYMDW** **7590 ± 80**  
 $\delta^{13}C = -26.2\%$

Charcoal (identified as *Corylus* and *Salix/Populus*) twigs and young branchwood, from organic river sediments overlying Pleistocene gravels and sealed by river gravel.

*Comment* (MAR): sample was well stratified, sealed beneath layer of gravel, peat, then clays; assoc with floral and faunal assemblage of late Flandrian Zone I.

**HAR-8355. HYMDO** **6540 ± 80**  
 $\delta^{13}C = -27.6\%$

Wood (identified as young branchwood of *Alnus*, *Quercus* and *Fraxinus* sp) AML 8650015, from hollow filled with organic river sediments on former bed of River Windrush.

*Comment* (MAR): deposit yielded faunal and floral assemblage of Flandrian Zone II.

**HAR-8356. HYMDG**

**10,860 ± 130**  
 $\delta^{13}C = -30.3\%$

Wood (identified as *Betula* and *Salix/Populus* sp) twigs, AML 8650012, from organic deposit in base of small channel sealed beneath uppermost Pleistocene gravels.

*Comment* (MAR): deposit yielded faunal and floral assemblage of Late Devensian.

**HAR-8366. HYMD/TS2**

**9530 ± 110**  
 $\delta^{13}C = -31.0\%$

Highly organic silt, AML 8650013, from base of channel cutting Pleistocene gravels.

*Comment* (MAR): sampled deposit was sealed beneath alluvial clays and yielded faunal and floral assemblage of early Flandrian Zone I. Stratigraphically later than HYMDG (HAR-8356).

*General Comment*: four latest samples in this series (HAR-8354 to -8355 and -8366) were studied for plant and invertebrate remains and provided sequence from Late Devensian to Flandrian Zone II. They provide first dated pre-Neolithic paleoecologic sequence for Upper Thames valley. Dates also relate latest Paleolithic flints from site to vegetational sequence.

**Trelan series****HAR-4538. 41-041**

**3040 ± 90**  
 $\delta^{13}C = -24.2\%$

Charcoal, AML 8110722, from backfill layer near top of Phase 2 ditch of round barrow at Trelan 2. Coll June 1981 by G Smith and subm Aug 1981 by N D Balaam, Central Excavation Unit.

**Rowden series**

Charcoal from Rowden, Dorset. Coll Sept 1981 by P J Woodward, Trust for Wessex Archaeol, and subm Oct 1982 by D Haddon-Reece, Historic Buildings and Monuments Comm, (Woodward 1981).

**HAR-5246. RD82523**

**5250 ± 140**

AML 822636, from Layer 523.

$\delta^{13}C = -26.3\%$

*Comment* (PJW): closely conforms to dates of HAR-5248 (4860 ± 70 BP) and HAR-5247 (4940 ± 70 BP), from base of same pit. Plain Early Neolithic Hembury-type wares were recovered from pit infill.

**HAR-5249. RD82837**

**2920 ± 80**

AML 822639, from entrance posthole (841) of Middle Bronze Age hut.  $\delta^{13}C = -26.8\%$

*Comment* (PJW): date is compatible with those of carbonized grain in storage pit (HAR-5698, 2920 ± 80 BP).

## Caldecotte series

**HAR 5616. MK117/04** **1750 ± 100**  
 $\delta^{13}C = -27.6\text{‰}$

Charcoal (identified as *Quercus* sp) AML 824007, from MK117, context 100, primary silt of ditch 4 in sect F, dark blue/gray black clayey silt with much organic material at Caldecotte, Mill Field site. Subm June 1983 by M Petchey, Bradwell Abbey Field Centre.

## Cowleaze series

**HAR-5618. 838** **3110 + 80**  
 $\delta^{13}C = -24.5\text{‰}$

Charcoal (identified as *Quercus* sp and *Pomoideae*) AML 831128, from soil (Sample 90) at top of accumulated soil profile in barrow ditch at Cowleaze, Winterbourne Stepleton, Dorset. Coll and subm June 1983 by P J Woodward.

*Comment* (PJW): this sample, at top of soil profile provided date 280 yr later than that at base of profile (HAR-5617, 3390 ± 100 BP) (Woodward 1982).

## Oxford St Aldate's series

Samples from 89, St Aldates, Oxford (51°44'53" N, 1°15'25" W, NGR SP513058) (Durham 1977; 1984). HAR-5344 coll and subm Oct 1982 by B G Durham, Oxford Archaeol Unit; all other samples coll June and subm Dec 1985 by B G D.

**HAR-5344. OXTMS32** **920 ± 100**  
 $\delta^{13}C = -29.8\text{‰}$

Charcoal, AML 826489, from mid-late Saxon gully.

**HAR-8360. OXTMS713** **1020 ± 70**  
 $\delta^{13}C = -27.4\text{‰}$

Leather, offcuts, apparently new rather than scrap, AML 872547, from within thick gravel feature, evidently causeway across flooded mill stream.

*Comment* (BGD): result confirms date of causeway construction due to flooding.

**HAR-8361. OXTMS626** **2280 ± 100**  
 $\delta^{13}C = -31.6\text{‰}$

Peat, marsh deposit with phragmites rhizomes, AML 872546, from extensive deposit of fine clay cut by mill stream.

*Comment* (BGD): causeway had apparently been constructed from this deposit.

**HAR-8362. OXTMS615** **1080 ± 80**

Wood (identified as *Alnus/Corylus*) twig, AML 872543, from mill stream.

*Comment* (BGD): results for samples HAR-8362 to -8364 confirm date of mid- or late-Saxon Thames causeway assumed to be constructed from upcast of mill stream.

<b>HAR-8363. OXTMS623</b>	<b>1180 ± 70</b>
Wood (identified as <i>Corylus</i> sp) AML 872544.	$\delta^{13}C = -25.9‰$
<b>HAR-8364. OXTMS625</b>	<b>1210 ± 70</b>
Wood, identified as <i>Alnus/Corylus</i> twig, AML 872545.	$\delta^{13}C = -26.2‰$

### Easton Lane series

Antler and bone samples from Easton Lane Interchange, Winchester, Hampshire (51°4'16" N, 1°17'26" W, NGR SU 497305). Coll by and subm Sept 1983 by P J Fasham, Trust for Wessex Archaeol.

<b>HAR-6115. ELI217</b>	<b>3350 ± 100</b>
Antler, AML 833178, from upper fill of late Neolithic pit. Coll Aug 1982.	$\delta^{13}C = -20.4‰$

*Comment* (PJF): dated to confirm contemporaneity of apparently related features of late Neolithic complex and to help date ceramic sequence.

<b>HAR-6118. ELI222</b>	<b>2260 ± 100</b>
Animal bone, AML 833181, from posthole ca 40cm deep of small, oval structure with large, closely-spaced postholes. This unusual feature is isolated at junction of two Bronze Age linear ditches. Coll Oct 1982.	$\delta^{13}C = -22.3‰$

*Comment* (PJF): dated to place oval structure, reminiscent of Late Neolithic or Early Bronze Age, into its chronologic position at site.

<b>HAR-6120. ELI 1193</b>	<b>2530 ± 100</b>
Bone, AML 833183, from basal Layer 687, of infilling of Bronze Age house terraced into N-facing slope. Coll Nov 1982.	$\delta^{13}C = -22.4‰$

*Comment* (PJF): houses and assoc pits form discrete part of prehistoric landscape 275m from nearest Bronze Age structure but with potentially contemporary cemetery only 75m N. Dates assoc cultural material in fill of house and general ceramics sequence of site.

<b>HAR-6122. ELI 459</b>	<b>2740 ± 70</b>
Bone, human limb, AML 833185, from inhumation assoc with shale and amber beads. Coll Oct 1982.	$\delta^{13}C = -22.1‰$

*Comment* (PJF): result will help establish date of unusual mixed cremation and inhumation open cemetery.

**Kynnersley series**

**HAR-6392. 257-115** **2110 ± 90**  
 $\delta^{13}C = -25.1\text{‰}$

Charcoal (identified as *Quercus* sp and *Salix/Populus*) mature wood, AML 8314022, from lower levels of gully surrounding excavated round house at Wall Fort Kynnersley (52°45'30" N, 2°28'27" W, NGR SJ 682179). Coll June 1983 and subm Sept 1984 by N D Balaam.

**Chester series**

**HAR-6625. HSS8169** **1490 ± 70**  
 $\delta^{13}C = -21.7\text{‰}$

Animal bone, from extensive layer of dark brown soil and rubble over Roman fortress buildings, containing Roman, late Saxon and some Medieval pottery. Late Saxon building was found on adjacent site and undatable, sunken-featured building was found nearby at Hunter St School, Chester. Coll 1981 and subm April 1984 by P Carrington, Grosvenor Mus, Chester.

**Heslerton Parish series**

Human bone from Heslerton Parish Proj, Vale of Pickering (54°10'40" N, 0°35'36" W, NGR SE 918767). Subm Oct 1984 by D J Powlesland.

**HAR-6631. HP00017C** **3510 ± 80**  
 $\delta^{13}C = -21.9\text{‰}$

Juvenile 13-14 yr old, AML 841217, from Context IR304 in Early Bronze Age (EBA) barrow.  
*Comment* (DJP): secondary burial with Beaker and inserted into grave of Skeleton IR340 (HAR-6630), whose bones were stacked at foot of grave.

**HAR-6907. HP00006C** **1840 ± 90**

AML 841206, from grave, Context 2B00084.

*Comment* (DJP): one of group of burials with weapons, situated at supposed center of burial.

**HAR-8241. HP00013C** **3510 ± 40**

AML 841213, Context 1L00110, EBA Barrow Cemetery 1.  $\delta^{13}C = -21.0\text{‰}$

*Comment* (DJP): secondary burial inserted through mound within year of mound construction, probably some time after primary burials.

**HAR-8242. HP00004C** **1510 ± 40**

AML 841204, from Context 2F00012, Anglian cemetery.  $\delta^{13}C = -20.6\text{‰}$

*Comment* (DJP): burial included bent spear and cut Grave 2F00013.

**HAR-8243. HP00005C** **1610 ± 40**  
 $\delta^{13}C = -20.3\text{‰}$

AML 841205, from Context 2F00013, Anglian cemetery, cut by Grave 2F00012.



*Comment* (DJP): burial included cruciform brooch with runic inscription.

**HAR-8325. HP00020C** **3640 ± 40**

Juvenile 7-9 yr old, AML 841220, from Context IR101, Iron Age burial inserted into EBA burial.

*Comment* (DJP): buried with Arras-type pot.

**HAR-8326. HP00014C** **3440 ± 40**

AML 841214, from context 1100131, EBA Barrow Cemetery 1.  $\delta^{13}C = -21.8\text{‰}$

*Comment* (DJP): tertiary burial cut through entirely filled barrow ditch.

### Cairn 38 series

Charcoal samples from Chysauster, CEU site 267, Carnaquidden Farm, Ludgvan, Cornwall (50°9'50" N, 5°32'25" W, NGR SW472354). Coll March 1984 by G Smith and subm by N D Balaam, Feb and May 1985.

**HAR-6652. 8410216** **3740 ± 90**  
 $\delta^{13}C = -25.5\text{‰}$

Identified as *Quercus* sp, AML 8410216, from fill of pot containing cremation burial; pot was in pit near center and below cairn.

*Comment* (GHS): HAR-6652 and -6654 date both burial and decorated pot containing it and will help sequencing Bronze Age pottery in S W, which is, at present, hypothetical.

**HAR-6654. 8410210** **3110 ± 70**  
 $\delta^{13}C = -24.5\text{‰}$

Identified as *Quercus* sp, AML 8410210, from fill of pot containing cremation burial. Pot was in pit outside kerb of cairn.

**HAR-6925. 8410168** **4570 ± 120**  
 $\delta^{13}C = -26.5\text{‰}$

Identified as mainly *Quercus* sp with some *Corylus avellana*, AML 8410168, from buried soil in positive lynchet which is one element of widespread field system physically continuous with Romano-British settlement but probably of Bronze Age origin.

*Comment* (GHS): dates phase of agricultural activity for which there is abundant physical evidence but no assoc cultural material, although field system may well have Bronze Age origins.

**HAR-6926. 8410157** **3150 ± 90**  
 $\delta^{13}C = -25.7\text{‰}$

*Quercus* sp, AML 8410157, from fill of pit containing cremation, outside the kerb of the cairn. One of six pits with probable cremations found around cairn but without burial pots.

*Comment* (GHS): date acts as sample of six unaccompanied burials and comparison with dates for burials containing pots.

**HAR-6927. 8410178** **3280 ± 120**  
 $\delta^{13}\text{C} = -26.3\text{‰}$

*Quercus* sp, AML 8410178, from fill of pit containing cremation and rimsherd of decorated pottery. Pit was close to but outside rim of cairn containing burial pots.

*Comment* (GHS): needed to date burial and assoc potsherd because whole sequence of Bronze Age pottery in the SW is, at present, hypothetical.

#### Ham Hill series

**HAR-6653. 252/84** **2160 ± 90**

Charcoal (identified as *Alnus* sp) AML 8312852, from lens of charcoal and carbonized grain in Iron Age pit at Ham Hill. Coll 1983 by GHS and subm April 1985 by NDB.

*Comment* (NDB): compares with earlier sample (HAR-6222) from site, dated to 1640 ± 80 BP.

#### Greyhound Yard series

Charcoal identified as oak (*Quercus* sp) from large timbers at Greyhound Yard, Dorchester, Dorset (50°42'50" N, 2°26'3" W, NGR SY69359064). Coll May 1984 by C J S Green and subm Aug 1984 by P J Woodward.

**HAR-6686. W67.1648** **4020 ± 80**  
 $\delta^{13}\text{C} = -27.0\text{‰}$

AML 845009, from infill on outer edge of postpipe, Late Neolithic Postpit 1647/1635.

**HAR-6687. W67.1649** **4090 ± 70**  
 $\delta^{13}\text{C} = -25.9\text{‰}$

AML 845010, from 'festoons' along edge of inner postpipe, Late Neolithic Postpit 1647/1635.

**HAR-6688. W67.1653** **4080 ± 70**  
 $\delta^{13}\text{C} = -26.5\text{‰}$

AML 845009, from 'festoons' in lower postpipe fill, Late Neolithic Postpit 1639/1631.

**HAR-6689. W67.1642** **4140 ± 90**  
 $\delta^{13}\text{C} = -26.3\text{‰}$

AML 845009, from fill of postpipe, Late Neolithic Postpit 1639/1631.

*General Comment* (PJW): results establish dates of postpits which are otherwise dated on form and flint assemblages alone to Late Neolithic (Woodward, Davies & Graham 1984). This is series of postpits in linear arrangement structurally similar to postpits at Mt Pleasant/Durrington Walls.

#### Honeygore Complex series

Wood samples from Honeygore Complex, Westhay Level, Somerset (51°9'50" N, 2°50'12" W, NGR ST415409). Coll and subm June 1985 by J M Coles, Somerset Levels Proj (Coles & Hibbert 1975; Coles *et al* 1985; Coles, Caseldine & Morgan 1988).

**HAR-6698. SLP8503** **4720 ± 70**  
 $\delta^{13}C = -29.6\text{‰}$

Identified as birch and hazel, AML 852742, from previously unknown Neolithic track in complex of at least five such tracks.

*Comment* (JMC): series of tracks in close proximity suggests Neolithic interest in immediate area. Dating relates track to immediate complex.

**HAR-6699. SLP8504** **4640 ± 70**  
 $\delta^{13}C = -27.8\text{‰}$

Identified as birch, AML 852743, from 1 of 5 Neolithic structures in Honeygore complex, Site no. Hdew 85.29.

*Comment* (JMC): Neolithic trackways in this area of Levels have been known for several decades, but until recently were lost from view. Renewed cutting in area is now intensive, and this site was destroyed within one day of its excavation. Date relates the track to adjacent ones.

#### Dalton Parlours series

Bones from multi-phase Iron Age occupation site (Hedges 1980) at Dalton Parlours, Collingham Parish, Wetherby, W Yorkshire (53°53'42" N, 1°23'18" W, NGR SE402445). Subm March 1985 by J D Hedges, Archaeol Unit, Wakefield, W Yorkshire.

**HAR-6715. DP602** **2140 ± 70**

AML 852639. Coll May 1977 by A B Sumpter.

**HAR-6725. DP764SS3** **2320 ± 90**

AML 852637. Coll March 1985 by JDH.  $\delta^{13}C = -23.7\text{‰}$

**HAR-6726. DPO201** **2950 ± 100**

AML 852638. Coll May 1977 by ABS.  $\delta^{13}C = -23.3\text{‰}$

**HAR-6727. DP0062** **2320 ± 120**

AML 852639. Coll March 1985 by JDH.

*Comment*: larger than normal error term reflects smaller than optimum size for liquid scintillation counting.

*General Comment* (JDH): Dalton Parlours has several acres of linked irregular single-ditched enclosures within which were round houses and other typical Iron Age structures. A large Roman villa was built after a break in occupation and thereafter some Anglo-Saxon activity is suspected. Few datable artifacts were retrieved from either Iron Age or Anglo-Saxon periods; thus,  $^{14}C$  samples are of considerable importance in interpreting the site.

#### Fiskerton series

Wood from Fiskerton (Field 1986) (53°13'51" N, 0°25'37" W, NGR TF050716). Coll 1981 by N Field and subm 1984 by J Hiram, Univ Sheffield.

**HAR-6728. FISK116** **2450 ± 70**

Tree rings sampled date to 436-405 BC.  $\delta^{13}C = -23.9\text{‰}$

**HAR-6729. FISK149** **2630 ± 70**

Tree rings sampled date to 433-405 BC.

**HAR-6730. FISK253** **2480 ± 70**

Tree rings sampled date to 500-455 BC.  $\delta^{13}C = -24.9\text{‰}$

*General Comment (JH):* chronology of Fiskerton Iron Age causeway has now been determined by dendrochronology (Hillam 1987).

#### Fulham Palace Moated Site series

From Fulham Palace moated site, Greater London, (51°28'15" N, 0°12'36" W, NGR TQ24327624). Coll Feb 1984 and subm by K R Whitehouse.

**HAR-6807. FPMS10** **1450 ± 70**  
 $\delta^{13}C = -26.1\text{‰}$

Silt with organic content, AML 840133 and submitter's ref MTIII, from moat, prior to relining. Subm March 1985.

**HAR-6841. FPMS17** **1710 ± 110**  
 $\delta^{13}C = -27.7\text{‰}$

Wood, AML 840181, from what appears to be moat lining. Subm Feb 1985.

*Comment (KRW):* sample taken to date moat's construction.

#### Manor Farm series

Human bones from Manor Farm, Borwick, Lancashire (54°8'45" N, 2°44'44" W, NGR SD513725) (Olivier 1983).

**HAR-6857. MF82SF73** **3440 ± 70**  
 $\delta^{13}C = -22.3\text{‰}$

AML 837244, from part of *in situ* primary inhumation, inside cell in limestone boulder enclosure, lying directly on truncated subsoil, underlying main body of cairn material. Coll Oct 1982 and subm Feb 1985 by A C H Olivier, Univ Lancaster.

*Comment (ACHO):* central burial included Early Bronze Age flat axe and dagger as did second *in situ* burial. Although a direct relationship between these two burials cannot definitely be proven, they are both in a primary stratigraphic position and likely to be broadly contemporary.

**HAR-7012. MF82SF44** **1530 ± 90**

AML 867676.  $\delta^{13}C = -21.7\text{‰}$

**HAR-7013. MF82SF46** **1220 ± 90**

AML 867677.  $\delta^{13}C = -23.0\text{‰}$

**HAR-7014. MF82SFBB** **2690 ± 100**

AML 867678.  $\delta^{13}C = -23.0\text{‰}$

*General Comment:* HAR-7012, -7013, -7014 come from scatter of human bone recovered during removal of main body of cairn (002), which overlay limestone enclosure (008). Coll 1982 and subm April 1986 by ACHO. Samples were dated to establish extent of possible Iron Age re-use (HAR 5659: 480 BC) of Bronze Age Burial Monument (HAR-5626, -5658, -5661: 1680 BC, 1320 BC, 1430 BC). Samples could result from later intrusion into main part of cairn.

#### Milton Lilbourne series

**HAR-6921. CO69MLB4** **3530 ± 110**  
 $\delta^{13}C = -25.2\text{‰}$

Charcoal (*Prunus* sp) AML 850047, from occupation soil added to loam core of high bell-barrow. Sample taken from base of barrow 4 at Milton Hill Farm, Milton Lilbourne, Wiltshire (51°19'8" N, 1°42'47" W, NGR SU19995784). Coll Aug 1958 and subm Oct 1984 by P Ashbee.

*Comment (PA):* date is useful *terminus post quem* for charcoal element of occupation earth additive, which could be older than barrow, although pottery content suggests contemporaneity (Annable 1958).

#### Potterne series

Charcoal samples from Potterne, near Devizes, Wiltshire (51°19'50" N, 2°0'21" W, NGR ST996591). Coll Aug 1984 and subm Dec 1985 by C Gingell and A J Lawson, Trust for Wessex Archaeol. All samples come from two middens and were intended to date sequence of midden and underlying deposits (Gingell & Lawson 1984; Gingell & Lawson 1985).

**HAR-6978. POTT1** **2590 ± 80**  
 $\delta^{13}C = -26.6\text{‰}$

Identified as *Quercus* sp, *Pomoideae* (hawthorn type), *Corylus avellana*, *Ulmus* sp, *Prunus* sp and *cf spinosa* (sloe), AML 858590, from midden, Context 1617, Column 88.

**HAR-6979. POTT2** **2490 ± 70**  
 $\delta^{13}C = -26.7\text{‰}$

Identified as *Quercus* sp, *Pomoideae* (hawthorn type), *Corylus avellana*, *Ulmus* sp, *Prunus* sp, *Fraxinus excelsior*, *Acer campestre* and *Ilex aquifolium*, AML 858591, from midden, Context 1608, Column 89.

**HAR-6980. POTT3** **2650 ± 80**  
 $\delta^{13}C = -24.0\text{‰}$

Identified as *Quercus* sp, *Pomoideae* (hawthorn type), *Ulmus* sp, *Prunus* sp (cherry/sloe), *Prunus spinosa*, *Fraxinus excelsior*, *cf Tilia* sp, AML 858592, from Context 2209, Column 88.

**HAR-6981. POTT4** **2630 ± 70**  
 $\delta^{13}C = -26.6\text{‰}$

Identified as *Quercus* sp, *Pomoideae* (hawthorn type), *Corylus avellana* (hazel), *Ulmus* sp, *Prunus* sp, *Prunus spinosa*, *Acer campestre* cf *Tilia* sp, AML 858593, from midden, Context 2208, Column 89.

**HAR-6982. POTT5** **3130 ± 100**  
 $\delta^{13}C = -25\text{‰}$

Identified as *Quercus* sp, *Pomoideae* (hawthorn type), *Corylus avellana*, *Prunus* sp (cherry/sloe), *Prunus* cf *spinosa*, fragments of twigs and larger wood, AML 858594, from Context 2988, Column 88.

**HAR-6983. POTT6** **3430 ± 110**  
 $\delta^{13}C = -26.8\text{‰}$

Fragments of twigs and larger wood, identified as *Quercus* sp, *Pomoideae*, *Corylus avellana*, *Prunus* sp, *Prunus spinosa*, *Tilia* sp, AML 858595, from Context 2984, Column 89.

#### Hasholme series

Peat from Hasholme Farm, Holme-on-Spalding Moor, N Humberside, (53°46'59" N, 0°45'8" W, NGR SE822326). HAR-7005 to -7007, coll Aug 1984 and subm April 1986 by M Millett, Univ Durham.

**HAR-7005. HAS174** **2530 ± 70**  
 $\delta^{13}C = -30.3\text{‰}$

AML 865982, from top of sequence, immediately prior to marine transgression.

**HAR-7006 HAS214** **2830 ± 70**

AML 865981, from lime decline in middle of sequence.  $\delta^{13}C = -30.8\text{‰}$

**HAR-7007. HAS430** **5710 ± 100**  
 $\delta^{13}C = -26.7\text{‰}$

AML 865983, from lime decline at base of sequence, dating marine regression.

*General Comment* (MM): dates help establish chronology of pollen record and marine transgression in relation to logboat (McGrail & Millett 1985; Millett & McGrail 1987).

**HAR-7024. HAS118** **3230 ± 90**  
 $\delta^{13}C = -26.7\text{‰}$

Wood, identified as oak, AML 865800, from near Hasholme logboat, rings 120 to 139 of bog oak, one of group at Hasholme. Coll 1984 by MM and subm March 1986 by J Hillam, Univ Sheffield.

*Comment* (JH): dated to find out whether bog oaks are roughly contemporary with logboat. Timber for boat felled 322-277 BC, so bog oak 118 is considerably older. Other bog oaks still to be dendrodated.

**North Down, Margate series**

Charcoal from North Down Park Estate, Margate, Kent (51°22'56" N, 1°25'41" E, NGR TR38507045). Coll Aug 1984 by GHS and subm Dec 1985 by N D Balaam (Smith 1988).

**HAR-7010. 274-1327** **3020 ± 80**  
 $\delta^{13}C = -25.4\%$

Identified as mostly *Pomoideae*, some *cf Prunus spinosa*, AML 841327, immediately underlying layer of Late Bronze Age rubbish in ring ditch of 'saucer' barrow.

*Comment* (GHS): dates *terminus post quem* for deposition of Late Bronze Age (LBA) rubbish layer.

**HAR-7011. 274-1298** **2910 ± 70**  
 $\delta^{13}C = -25.6\%$

Identified as mostly *Pomoideae* with some *Quercus* sp and *Corylus* sp, AML 841298, from small cremation pit within 'saucer' barrow.

*Comment* (GHS): dates one phase of barrow use.

**Brean Down series**

Charcoal from Brean Down Sandcliff, Brean, near Burnham-on-Sea, Somerset (51°19'21" N, 3°0'43" W, NGR ST295587) (Bell 1986; ApSimon, Donovan & Taylor 1961). Subm Nov 1985 by M Bell, St David's Univ Coll, Lampeter.

**HAR-7016. BD5801-1** **3420 ± 100**  
 $\delta^{13}C = -26.5\%$

Twigs and fragments, AML 865783, from feature, Context 103, sealed by compacted clay floor, Context 60, of stone roundhouse of probable Middle Bronze Age (MBA) date. Coll Sept 1985 by Helen Smith.

*Comment* (MB): Context 103 is cut into base of terrace occupied by building. Dates initial activity in this occupation horizon and compares with overlying floor (HAR-7017). Two dates provide information on duration of occupation in Unit 56 of sandcliff sequence.

**HAR-7017. BD5749-2** **2730 ± 100**  
 $\delta^{13}C = -25.5\%$

AML 865784, from hard-packed clay floor of stone roundhouse of probable MBA. Coll Sept 1985 by HS.

*Comment* (MB): Context 60 is floor of Bronze Age Structure 59. Dates structure and compares with underlying pit (HAR-7016) and two other Bronze Age structures, one broadly contemporary, Structure 95, HAR-7019, one, Structure 57, HAR- 7020, clearly earlier on stratigraphic grounds, being separated from the other two by sand.

**HAR-7018. BD5803-3** **2870 ± 100**  
 $\delta^{13}C = -25.1\%$

AML 865786, from area of burning, Context 93, assoc with clay hearth in center of floor of

well preserved Bronze Age roundhouse, Structure 95. Coll Sept 1985 by K Watson.

*Comment* (MB): dates final phases of use of Structure 95. Can be compared with BD 6013-4 (HAR-7019) from wall of same structure and other Bronze Age structures on site.

**HAR-7019. BD6013-4** **2940 ± 100**  
 $\delta^{13}C = -25.4\text{‰}$

AML 865788, from stone wall, Context 131, of Bronze Age roundhouse Structure 95. Coll Sept 1985 by MB.

*Comment* (MB): dates construction of Structure 95. Can be compared with HAR-7018, hearth charcoal from floor of this structure and with dates from two other Bronze Age structures at site.

**HAR-7020. 6153-5** **3310 ± 80**

AML 865789, from floor, Context 163, of oval stone-built Bronze Age Structure 57, separated from overlying Bronze Age occupation horizon by blown sand. Coll Sept 1985 by MB.

*Comment* (MB): dates Structure 57 and can be compared with dates from two overlying structures and underlying colluvial deposit, 6 and 7.

**HAR-7021. BD5886-6** **2600 ± 90**  
 $\delta^{13}C = -27.1\text{‰}$

AML 865790, from lenses of burned material representing occupation activity in gleyed colluvium that abuts or antedates Structure 57; separated from Structures 59 and 95 by blown sand. Coll Sept 1985 by B Muir.

*Comment* (MB): measured to date occupation activity assoc with colluvium and relationship of this layer to Structure 57 and underlying ungleyed colluvium (HAR-7022).

**HAR-7022. BD6062-7** **3890 ± 130**  
 $\delta^{13}C = -26.0\text{‰}$

AML 865791, from ungleyed colluvium underlying the gleyed colluvium from which BD 5886-6 (HAR-7021) was taken. Coll Sept 1985 by BM.

*Comment* (MB): dates colluviation which interrupted sand blow and relationship to underlying blown sand with Beaker artifacts and overlying structural evidence.

**HAR-7023. BD6171-8** **4720 ± 140**  
 $\delta^{13}C = -24.6\text{‰}$

AML 865792, from paleosol representing basal layer of postglacial sequence. Coll Sept 1985 by BM.

*Comment* (MB): layer from which sample was taken had previously produced Grooved ware and Beaker burial. During this excavation it produced an (?earlier Neolithic) leaf-shaped arrowhead. Dated for time of initial activity on site.

### Spong Hill series

Charcoal samples from Spong Hill, near North Elmham, Norfolk (52°41'32" N, 2°24'39" E, NGR TG980197).



**HAR-7025. 10123645** **8250 ± 90**  
 $\delta^{13}C = -26.2‰$

AML 865776, from Neolithic pit with Mildenhall Ware. Coll 1984 by A Rogerson and subm March 1986 by P Murphy, Univ East Anglia.

*Comment* (PM): it is unclear how far Early/Middle Neolithic occupation of site was single-period and how far it was multicomponent. Stylistic features of some of the Neolithic pottery suggest that occupation was continuous through third millennium BC, but this is not clear from the other  $^{14}C$  results.

**HAR-7063. SPON3408** **8280 ± 80**  
 $\delta^{13}C = -24.6‰$

AML 858566, from layer of burned sand and gravel, Context 3408=3594, in feature, Context 3367, containing struck flint of later Mesolithic character throughout its fills. Coll autumn 1985 by A Rogerson and subm Oct 1985 by P Murphy.

#### Crane Wharf series

Wood from W112, Crane Wharf, Reading, Berkshire (51°27'15" N, 0°57'55" W, NGR SU71897335). Coll Nov 1985 and subm April 1986 by John Terry, Trust for Wessex Archaeol.

**HAR-7026. W112187** **1970 ± 70**  
 $\delta^{13}C = -30.1‰$

AML 865793, from layer of brown organic rich silt, similar to peat.

**HAR-7027. W112188** **4990 ± 60**  
 $\delta^{13}C = -32.4‰$

Large fragments from mixture of species, AML 865794, from layer of gravel/sand beneath brown organic-rich silt.

**HAR-7028. W112195** **4950 ± 80**  
 $\delta^{13}C = -27.5‰$

Identified as *Alnus glutinosa*, large timber, AML 865795, from Layer 188, gravel sand overlying laminated sands and gravels.

*Comment* (JT): measured for prehistoric date of assoc deposits.

#### East Heslerton Long Barrow series

Charcoal from post in facade bedding trench at E end of long barrow at East Heslerton Wold, near Malton, North Yorkshire (54°9'53" N, 0°33'47" W, NGR SE938753). Coll 1962 by F de M Vatcher and subm Jan 1986 by T G Manby, Doncaster Mus and Art Gallery (Vatcher 1965).

**HAR-7029. EHLB1** **4920 ± 90**  
 $\delta^{13}C = -24.5‰$

AML 865779.

**HAR-7030. EHLB2** **5020 ± 70**  
 $\delta^{13}C = -25.9‰$

AML 865780.

**HAR-7031. EHLB3** **5020 ± 110**  
 AML 865781.  $\delta^{13}C = -26.0\text{‰}$

**HAR-7032. EHLB4** **4640 ± 70**  
 AML 865782.  $\delta^{13}C = -25.0\text{‰}$

*General Comment (TGM):* result should date facade structure. This is most developed facade structure known from Yorkshire Long Barrow groups.

#### Ferring series

Charcoal from Ferring, near Littlehampton, West Sussex (50°48'37" N, 0°27'15" W, NGR TQ089024). Coll 1984 by P L Drewett and subm 1985 by C Cartwright, Inst Archaeol, London.

**HAR-7033. FRA16** **2800 ± 70**  
 $\delta^{13}C = -26.6\text{‰}$

AML 858587, from Trench A, Context 16, layer of dark brown clay and silt containing organic material and burned flint, on coastal plain adjacent to the Ferring Rife.

**HAR-7034. FRA43** **3040 ± 70**  
 $\delta^{13}C = -24.8\text{‰}$

AML 858588, from Trench A, Context 43, layer of charcoal and burned flint.

**HAR-7035. FRB42** **2360 ± 70**  
 $\delta^{13}C = -26.0\text{‰}$

AML 858589, from Trench B, Context 42, dark brown, organic-rich humic layer with charcoal.

*General Comment (CC):* Trenches A and B at Ferring are adjacent to marine inlet which later became freshwater stream. Apart from burned flint and small assemblage of knapped flint, bulk of deposit was organic. A late Bronze Age hoard of metalwork was discovered in 1983 near site of 1984 excavations (Aldsworth & Kelly 1983).

#### West Heath Common series

Charcoal from West Heath Common, Sussex (50°59'49" N, 0°52'47" W, NGR SU786226). Coll 1984 by P L Drewett and subm 1985 by CRC.

**HAR-7036. 49883E99** **8770 ± 80**  
 $\delta^{13}C = -26.8\text{‰}$

AML 858585, from Trench 3E, Context 99, in very thin layer of dark brown sand containing charcoal, on Lower Greensand ridge.

*Comment (CC):* 1984 excavations were adjacent to barrows excavated in 1973-1975 to isolate sequences of environmental change and land use around barrow foci.

**HAR-7037. 49883103** **9040 ± 90**  
 $\delta^{13}C = -27.3\text{‰}$

AML 858586, from Context 103, Trench 3E, which is small lens of brown sand with many charcoal fragments.

#### Yapton series

**HAR-7038. 19841944** **2600 ± 70**  
 $\delta^{13}C = -26.4\text{‰}$

Charcoal (identified as *Quercus* sp, *Crataegus* sp, *Leguminosae*, *Salix/Populus*, *Corylus* sp) AML 858567, from Context 4, one of pit fills of Pit no. 2 at Yapton, W Sussex (50°48'47" N, 0°37'46" W, NGR SU96540245). Coll Aug 1984 by David Rudling and subm Sept 1985 by CRC.

*Comment* (CC): this is only Iron Age site on coastal plain that provides material suitable for dating in close assoc with pottery. By dating pit fill and pottery many valuable comparisons can be made from other coastal plain sites.

#### Stafford ST29 series

Charcoal and unidentified grain and plant remains, from well-defined deposit in chamber of grain-drying kiln at ST 29, St Mary's Grove, Stafford. Coll Sept 1983 and subm Oct 1985 by J H Cane, Stafford Archaeol Proj.

**HAR-7039. 29224701** **1270 ± 70**  
 $\delta^{13}C = -25.9\text{‰}$   
AML 859568.

**HAR-7040. 29224702** **1120 ± 70**  
 $\delta^{13}C = -26.3\text{‰}$   
AML 859569.

**HAR-7041. 29224703** **1310 ± 90**  
 $\delta^{13}C = -25.6\text{‰}$   
AML 859570.

*General Comment* (JHC): samples came from series of four similar and probably contemporary structures and were probably last firing of feature. Structures represent major Late Saxon activity at site but their position within 150 yr of pre-Conquest Stafford is unknown.

**HAR-7042. 29225301** **2290 ± 70**  
 $\delta^{13}C = -24.2\text{‰}$

Burned wood and grain mixed with other organic remains, AML 858571, from fill of posthole. Coll Oct 1983 and subm Oct 1985 by JHC.

*Comment* (JHC): posthole forms part of 4-post structure sealed by layer containing Romano-British pottery. It is one of two such structures that antedate main activity period, 10th century. Sealing layer is cultivation-derived and may be post-Roman.

#### Stafford ST32 series

Charcoal from ST 32, Tipping Street, Stafford (53°2'52" N, 2°6'48" W, NGR SJ924501). Coll

July 1983 by M D Taylor and subm Oct 1985 by JHC.

**HAR-8237. 32151601** **1150 ± 40**  
 $\delta^{13}C = -25.5\text{‰}$

AML 858572, from remains of last firing of kiln producing 'Stafford Ware' pottery.

*Comment* (JHC): this sample and HAR-8238 were recovered from just inside stokehole of kiln sealed by fragments of clay superstructure. Archaeomagnetic sampling gave range of AD 900 - AD 1100.

**HAR-8238. 32151602** **1140 ± 40**

AML 858573, from remains of last firing of kiln producing 'Stafford Ware' pottery.

**HAR-8239. 32175301** **1140 ± 40**  
 $\delta^{13}C = -26.0\text{‰}$

AML 858575, from Context 1753, deposit of burned material and ash just inside stokehole of 'Stafford Ware'-producing pottery kiln, F 238, (*cf* HAR-8240). These two deposits were directly assoc with several pits containing very large amounts of 'Stafford Ware'.

**HAR-8240. 32175302** **1120 ± 40**

AML 858576.  $\delta^{13}C = -26.0\text{‰}$

*General Comment* (JHC): kiln fairly intact and well-defined although its stratigraphic position was uncertain. It was visible in horizon tentatively dated to late 12th century though not in use at this time.

### Glastonbury series

Two samples of wood (probably *Thelycrania sanguinea* dogwood), small branch, from ca 9cm above base of large, silt-filled ditch, some 4m deep but of unknown width, since it is under street at Magdalen St Ditch, Glastonbury, Somerset (Ellis 1982). Coll March 1985 and subm by V Straker, Univ Bristol.

**HAR-7044. GLMS1** **950 ± 70**

AML 858569.  $\delta^{13}C = -28.9\text{‰}$

**HAR-7045. GLMS2** **1080 ± 80**

AML 858596.  $\delta^{13}C = -28.2\text{‰}$

*General Comment* (VS): dating determines whether ditch is W boundary of early monastic precinct. E side has already been dated.

**HAR-7046. CATF22** **1200 ± 70**  
 $\delta^{13}C = -20.2\text{‰}$

Bone, AML 858549, from Trench F, at W end of former N wall of nave in wall foundations. Foundations cut series of soily deposits one of which, Context F 22, was grave containing human

bones at Carlisle Cathedral, Carlisle, Cumbria (54°53'39" N, 2°56'14" W, NGR NY399559). Coll and subm Sept 1985 by M R McCarthy.

*Comment* (MRMcC): date confirms 7th - 11th centuries for this context and establishes for first time presence of ecclesiastical building below present cathedral.

#### Watkins Farm series

Samples from Watkins Farm, Northmoor, Oxfordshire (51°43'45" N, 1°23'4" W, NGR SP425 036). Coll and subm by T G Allen, Oxford Archaeol Unit.

**HAR-7051. NMWFMED1** **2290 ± 100**

Bone subm May 1986.

**HAR-7053. NMWF60** **2160 ± 70**  
 $\delta^{13}C = -28.4\text{‰}$

Wood, AML 858556, from large triangular waterlogged feature directly outside entrance to central roundhouse; 0.5m of peat were sealed by clay, silt and clay and gravel backfill. Coll Oct 1983 and subm Nov 1985.

*Comment* (TGA): this feature produced only assemblage of fish bones from site and may have been well serving Iron Age inhabitants of site.

**HAR-8253. NMWF498** **3060 ± 70**  
 $\delta^{13}C = -28.9\text{‰}$

Wood from burial in waterlogged pit. Coll Dec 1984 and subm Nov 1985.

*Comment* (TGA): burial extended around side of large deep pit or well, assoc with layers of burned limestones and several wooden and leather objects. This lay within penannular Iron Age gully, but produced very little pottery. Burial appears to be very unusual.

**HAR-8254. NMWF151** **2190 ± 70**  
 $\delta^{13}C = -25.2\text{‰}$

Charcoal from ditch immediately outside central roundhouse. Coll Oct 1983 and subm Oct 1986.

*Comment* (TGA): dates latest stages of occupation.

**HAR-8255. NMWF5531** **2060 ± 80**  
 $\delta^{13}C = -27.7\text{‰}$

Charcoal from hearth in enclosures attached to main settlement. Coll Oct 1983 and subm Oct 1986.

#### Blackwater series

Six wood samples and 1 charcoal from several Blackwater sites at Bradwell in Essex. All coll summer and subm Oct 1985 by P Murphy, Univ East Anglia.

**HAR-7054. BRA/79****2350 ± 70**  
 $\delta^{13}C = -26.0\text{‰}$ 

Wood (identified as *Quercus* sp) AML 858557, from one of series of wooden stakes (not fully planned) driven into submerged land surface at site of Middle Neolithic settlement, on intertidal flats close to nuclear power station at Blackwater Site 8, Bradwell, Essex (51°44'48" N, 0°54'43" E, NGR TM01000940).

*Comment* (PM): although assoc with Middle Neolithic settlement, there was no stratigraphic evidence to determine if stakes were contemporary with it.

**HAR-7055. B18/86****2790 ± 80**  
 $\delta^{13}C = -29.5\text{‰}$ 

Wood, AML 858559, from brushwood structure exposed on foreshore by marine erosion, on intertidal flats at Blackwater Site 18, Tollesbury, Essex (51°44'14" N, 0°48'45" E, NGR TL94180809).

*Comment* (PM): this structure was assoc with no artifacts, but its stratigraphic position suggested Late Bronze Age date.

**HAR-7056. B18/91****4030 ± 80**  
 $\delta^{13}C = -28.4\text{‰}$ 

Wood, AML 858561, from tree roots on land surface, sealed by estuarine sediments, Blackwater Site 18, Tollesbury, Essex (51°44'14" N, 0°48'45" E, NGR TL94180809). Sample assoc with Neolithic settlement.

*Comment* (PM): provides a *terminus post quem* for estuarine sedimentation and thus dates local marine transgression.

**HAR-7057. B28/96****2360 ± 70**  
 $\delta^{13}C = -28.6\text{‰}$ 

Wood, AML 858562, from wooden hurdle structure (3.5m x 0.8m) exposed by marine erosion on intertidal flats, Blackwater Site 28, Goldhanger, Essex (51°43'52" N, 0°45'13" E, NGR TL90140725). Structure consists of eight longitudinal poles with well-preserved smaller rods probably part of a trackway over mud flats.

*Comment* (PM): this impressive structure has no datable artifacts, but position suggests Late Bronze Age.

**HAR-7058. B28/98****1020 ± 80**  
 $\delta^{13}C = -30.1\text{‰}$ 

Wood, AML 858563, from brushwood structure, probably hurdle, on intertidal flats, Blackwater Site 28, Goldhanger, Essex (51°43'52" N, 0°45'13" E, NGR TL90140725). Structure is close to B28/96 (HAR-7057), and assoc with fired clay.

*Comment* (PM): structure was only superficially examined to avoid further erosion. It was thought to be Late Bronze Age from its elev; it was not overlain by later deposits.

**HAR-7059 B17/69****Modern** $\delta^{13}C = -26.4\%$ 

Wood, AML 858558, from double, sometimes triple, line of stakes extending for some 20m near low water mark, Blackwater Site 17, East Mersea, Essex (51°49'3" N, 0°27'1" W, NGR TL06801440). Line is parallel to coast and thought to be part of Medieval fish trap.

*Comment (PM):* structure had no datable artifacts; as it was not sealed by overlying strata late <sup>14</sup>C date is acceptable.

**HAR-7060. B18/90****4180 ± 70** $\delta^{13}C = -23.7\%$ 

Charcoal, AML 858560, from charcoal spread on submerged land surface on intertidal flats sealed beneath estuarine sediments at Blackwater Site 18, Tollesbury, Essex (NGR: TL94180809).

*Comment (PM):* sampled from submerged land surface 100m to SE of Neolithic Site 18 which yielded abundant Middle Neolithic pottery.

**Fishergate series****HAR-7061. 732/113****1150 ± 80**

AML 858564, top surface, at 113cm.

 $\delta^{13}C = -28.0\%$ **HAR-7062. 732/195****9410 ± 110** $\delta^{13}C = -31.4\%$ 

Phragmites peat, AML 858565, from base, at 190 - 195cm, from deposit just over 80cm thick underlying Late Saxon occupation deposits at Fishergate, Norwich, Norfolk (52°37'59" N, 1°17'59" E, NGR TG 23270907). Coll summer 1985 by B S Ayres and subm Oct 1985 by PM, Univ East Anglia.

*Comment (PM):* peat was also examined for pollen, plant macrofossils and insects to study pre-urban land use and vegetation. Middle Saxon pottery came from top of peat (*in situ* or pressed in) but base was completely undated.

**MVE 82 series**

From Meare Village East, Meare, Somerset (51°10'31" N, 2°47'30" W, NGR ST44664214). Coll April 1982 and subm Nov 1985 by A E Caseldine, Somerset Levels Project.

**HAR-7064. SLP8505****5270 ± 70** $\delta^{13}C = -30.0\%$ 

Peat, AML 857488, from end of local pollen assemblage boundary MVE.1/MVE.2. This sample (MVE82.188) is 1.88 - 1.89m below top of monolith.

**HAR-7065. SLP8506****4160 ± 70** $\delta^{13}C = -29.1\%$ 

Peat, AML 857489, from boundary of local pollen assemblage zones MVE.3/MVE.4. This sample (MVE82.114) is 1.14 - 1.15m below top of monolith.

**HAR-7066. SLP8507**

**2660 ± 70**  
 $\delta^{13}C = -31.8‰$

Soil, AML 857490, from 0.54 - 0.55m below top of monolith. This sample (MVE82.54) is 20cm below top of organic deposits and approx middle of local pollen assemblage zone MVE.6.

*General Comment* (AEC): basic stratigraphic sequence at Meare East Iron Age site consists of detritus peats and muds (ca 2m) overlain by alluvial clay (Beckett 1979; Beckett & Hibbert 1979; Orme, Coles & Silvester 1983). The three  $^{14}C$  dates enable local pollen assemblage zones to be delimited and correlated with regional pollen zonation already established at Levels.

**Beverley Eastgate series**

From Beverley Eastgate, Beverley, Humberside, (53°50'23" N, 0°25'20" W, NGR TA 03803935). Coll Nov 1984 by D G Tomlinson and subm Nov 1985 by P Armstrong, Humberside Co Council.

**HAR-7067. BE84/752**

**1280 ± 70**  
 $\delta^{13}C = -28.9‰$

Wood, AML 858073, from scatter of wood and twigs overlying an apparently natural silt and peat formation and sealed by further peat deposit.

**HAR-7068. BE84751**

**1200 ± 70**  
 $\delta^{13}C = -30.5‰$

Peat, AML 858074, from deposit of compact peat up to 35cm thick which formed over thin primary silt in natural hollow. This sample underlies HAR-7069 and overlies -7067.

**HAR-7069. BE841621**

**1470 ± 70**  
 $\delta^{13}C = -28.0‰$

Wood, AML 858075, from bundle of wattles lying at base of ditch cutting peaty deposit assumed to be natural.

*Comment* (PA): ditch was used for drainage reclamation and thus represents early settlement period.

**HAR-7070. BE841526**

**1000 ± 70**  
 $\delta^{13}C = -28.4‰$

Wood, AML 858076, from curving hurdlework fence representing first enclosing feature at site in what remained heavily organic soil with high water table. This sample is from top of sequence and overlies HAR-7069.

*General Comment* (PA): four samples establish chronology for site where no artifactual chronology is possible and also *terminus post quem* for occupation and settlement of site.

**Ewanrigg series**

Charcoal from Ewanrigg, Maryport, Cumbria (54°42'2" N, 3°29'51" W, NGR NY035350). Coll Aug and subm Oct 1985 by R H Bewley, Hist Buildings and Monument Comm.



**HAR-7071. EWR85052** **3400 ± 70**

AML 858542, from a cremation pit cut into subsoil.  $\delta^{13}C = -27.7\text{‰}$

*Comment* (RHB): only 3 of 29 cremation pits at this site have been dated.

**HAR-7072. EWR85037** **3570 ± 80**

AML 858543, from cremation pit containing fragments of coarse pottery.  $\delta^{13}C = -26.2\text{‰}$

*Comment* (RHB): of 29 cremation pits at this site few have good charcoal and even fewer have pottery. This has both and is very important for dating site.

**HAR-7073. EWR85072** **1260 ± 100**  
 $\delta^{13}C = -26.5\text{‰}$

AML 858544, from Context 72 which is tunnel-like 'entrance' to dry stone-walled circular pit.

*Comment* (RHB): this feature, along with stone chamber, was part of corn-drying kiln.

**HAR-7074. EWR85074** **1040 ± 80**  
 $\delta^{13}C = -27.9\text{‰}$

AML 858545, from Context 74, which is within stone-lined circular pit, with funnel like entrance way. Context 74 is primary silting layer of this chamber-like feature.

*Comment* (RHB): seed assemblage indicates this feature was corn-drying kiln.

**HAR-7075. EWR85059** **1250 ± 100**

AML 858546, from primary silt of chamber feature.  $\delta^{13}C = -25.4\text{‰}$

*Comment* (RHB): period of chamber is unknown, so date determines final use of chamber.

**HAR-7076. EWR85068** **810 ± 80**  
 $\delta^{13}C = -24.6\text{‰}$

AML 858547, from dark stains, probably stake holes; part of super-structure or resulting from use of chamber.

*Comment* (RHB): measured to date final use of stone chamber.

**HAR-7077. EWR85055** **3700 ± 120**  
 $\delta^{13}C = -27.1\text{‰}$

AML 858548, from cremation pit with enlarged food vessel (Longworth 1984).

*Comment* (RHB): measured to date enlarged food vessel.

#### **Cannington series**

Human bone, from grave in group in NE corner of cemetery, discrete and well-defined row of graves at Cannington, Somerset. Coll 1962-1963 by P A Rahtz and subm Aug 1984 by P A Rahtz, S Hirst and S Wright.

**HAR-8049. 401** **1390 ± 40**  
 Immature.  $\delta^{13}C = -20.2\text{‰}$

**HAR-8050. 419** **1460 ± 40**  
 Adult.  $\delta^{13}C = -20.5\text{‰}$

*Comment (SMH):* Roman and prehistoric finds in grave.

**HAR-8051. 404** **1370 ± 40**  
 Adult.  $\delta^{13}C = -20.2\text{‰}$

*Comment (SMH):* prehistoric and Roman finds in grave; pathological specimen - may have been leper.

**HAR-8052. 421** **1560 ± 40**  
 Adult.  $\delta^{13}C = -21.5\text{‰}$

**HAR-8053. 422** **1360 ± 40**  
 Immature.  $\delta^{13}C = -20.3\text{‰}$

*Comment (SMH):* prehistoric finds in grave.

*General Comment (SMH):* graves yielding these five samples (HAR-8049 to -8053) are broadly contemporary and may be family group. They are possibly assoc with summit structure FT43 which is thought to be early feature in cemetery.

#### Albany Road series

Wood, from silted-up former channel of River Exe, Albany Road, St Thomas, Exeter, Devon (50°42'55" N, 3°32'3" W, NGR SX 917918). Channel is 1.5m deep, filled with blue clay, with darker horizontal laminations containing wood, twigs and leaves. Coll May 1984 by V Straker and C Henderson and subm Sept 1985 by V Straker, Univ Bristol.

**HAR-8054. ALB2** **1240 ± 70**  
*Alnus* sp (alder) and *Corylus avellana* (hazel), AML 858579, from 36 - 44cm above base.

**HAR-8055. ALB3** **970 ± 80**  
 $\delta^{13}C = -28.2\text{‰}$

*Salix/Populus* (willow/poplar), AML 858580, from 112 - 116cm above base.

*General Comment (VS):* dating helps with palynology from lowland Devon and investigation of saline/freshwater conditions of Exe River.

#### Cowage Farm series

**HAR-8082. 245-172** **1220 ± 70**  
 $\delta^{13}C = -25.4\text{‰}$

Charcoal (*Quercus* sp) AML 8317536, from posthole in what is thought to be Middle Saxon

hall at Cowage Farm, Foxley (51°34' 27" N, 2°8'8" W, NGR ST 906862). Coll Aug 1983 by J Hinchliffe and subm March 1984 by N D Balaam, Central Excavation Unit.

**HAR-8083. 241-24** **4070 ± 80**  
 $\delta^{13}C = -21.4\%$

Adult human bone, 5th metatarsal, AML 8312200, from mound rubble of possible long barrow at Druids Hill, Stoke Bishop. Coll 1982 by G H Smith and subm Dec 1983 by NDB.

**HAR-8097. NKS2** **3550 ± 80**  
 $\delta^{13}C = -25.8\%$

Charcoal, AML 837116, from fire on old land surface at Nancekuke barrow, Cornwall (NGR SW67654627). Coll Aug 1940 by C Croft Andrew and subm July 1983 by P M Christie, Inst of Archaeol, London.

*Comment* (PMC): primary date for barrow (Christie 1985).

**HAR-8098. DM1652** **3440 ± 100**  
 $\delta^{13}C = -26.3\%$

Charcoal, AML 837122, from central deposit at Davidstow Moor, Barrow 16, Cornwall (NGR SW67654627). Coll June 1942 by CCA and subm July 1983 by PMC.

*Comment* (PMC): primary date for barrow (Christie 1985).

**HAR-8089. CAT54** **3510 ± 70**  
 $\delta^{13}C = -25.9\%$

Charcoal, AML 837113, from central fire area under cairn at Cataclews Barrow 1, Cornwall (NGR SX142584610). Coll 1944 by CCA and subm July 1983 by PMC.

*Comment* (PMC): primary date for cairn (Christie 1985).

**HAR-8100. TR254** **3380 ± 80**  
 $\delta^{13}C = -25.3\%$

Charcoal, AML 837119, from Burial 3 under slate kerb at Treligga Barrow 2, Cornwall (NGR SX04508559). Coll 1941 by CCA and subm July 1983 by PMC.

*Comment* (PMC): dates secondary burial in barrow (Christie 1985).

#### Wasperton series

Peat, leaves, twigs, plant material and charcoal from E bank of River Avon, Wasperton, Warwickshire (52°13'25" N, 1°36'43" W, NGR SP265585). Coll July 1985 by M Halliday and subm Feb 1986 by C Bowker and G Crawford, Birmingham Univ Field Archaeol Unit. Wasperton was a large gravel complex with little organic material surviving. Samples came from peat deposit adjacent to site (Bowker 1983; Crawford 1983; 1984).

**HAR-8103. WNPEAT1** **710 ± 80**

AML 8650603, from base of column (0 - 6cm).  $\delta^{13}C = -31.9\%$

**HAR-8104. WNPEAT2** **550 ± 80**  
 AML 8650604, from 6 - 15cm above base of column.  $\delta^{13}C = -32.0\%$

**HAR-8105. WNPEAT3** **500 ± 100**  
 AML 8650605, from 15 - 23cm above base of column.  $\delta^{13}C = -31.5\%$

**HAR-8106. 6644** **2940 ± 70**  
 $\delta^{13}C = -25.7\%$

Charcoal, AML 8650606, from lower fill of post pit. Context below 6644 comprised redeposited natural gravel. Sample 6644 was initial fill following withdrawing of post and indicates first phase of disuse. Coll Sept 1983 and subm Feb 1986.

*Comment (GC):* post pit was part of structure, possibly dwelling, different in character from adjacent Iron Age features. Some nearby postholes contained Neolithic 'Peterborough' pottery.

**HAR-8107. 5098** **2210 ± 80**  
 $\delta^{13}C = -26.0\%$

AML 8650607, from dense lens of charcoal close to base and just above cleaning slot of defensive ditch surrounding putative Iron Age settlement. Coll Feb 1985 and subm Nov 1985.

*Comment (GC):* defensive ditch from which sample came appeared to have been regularly cleaned but with short lifespan overall.

#### Jaywick series

Samples from gray clay fill of small pit exposed on foreshore at Clacton site 1 (Jaywick), Hullbridge Proj (51°46'29" N, 01°07'35" E, NGR: 15631312) (Wilkinson & Murphy 1984). Coll June 1984 and subm 1985 by P Murphy.

**HAR-8154. JAYSIC5** **3830 ± 80**  
 Charcoal.  $\delta^{13}C = -24.9\%$

*Comment (PM):* large fragments of Beaker (Lanting & van der Waals Step 3) from pit fill support this date.

**HAR-8368. JAYSIC2** **1420 ± 80**  
 Wood.

**HAR-8369. JAYSIC3** **380 ± 90**  
 Wood.  $\delta^{13}C = -25.4\%$

**HAR-8180. BH864526** **2200 ± 80**  
 $\delta^{13}C = -27.2\%$

Wood, identified as possibly alder, AML 8650144, from early raft or causeway, connecting former island to mainland, Butley Thrift, Burrow Hill, East Suffolk (52°4'57" N, 1°29'19" E, NGR TM 390485) (Fenwick 1984). Principal periods of island's occupation are Iron Age (Little Waltham

Period II) and Middle Saxon (ca 680-840). Coll Sept 1986 by Mrs V Fenwick and subm Sept 1986 by D Sherlock, Ancient Monuments Lab.

*Comment* (DS): sample is from wooden piles beneath 1m clay plus 85cm sand and humus. Wooden piles underlay marsh clay and causeway at -1.95m OD.

#### Hallshill series

Charcoal, part of a series of six from cutting A at excavated round house (Gates 1983) at Hallshill, Elsdon, Northumberland (55°11'33" N, 2°8'46" W, NGR NY907887). Coll Sept 1986 by S Hedley and subm Sept 1986 by T Gates, Univ Newcastle.

**HAR-8183. HAL-23** **2960 ± 60**  
 $\delta^{13}C = -27.2\%$

Identified as *Alnus* sp, AML 8650178, from small pit, Context 23, containing carbonized plant material, burned bone, burned stones and one undecorated pottery sherd.

*Comment* (TG): pit could be either cremation burial or rubbish deposit and antedates timber building.

**HAR-8184. HAL-21** **3130 ± 60**  
 $\delta^{13}C = -27.0\%$

Identified as *Corylus avellana*, AML 8650179, from 1 of 9 postholes constituting inner ring of roof supports of excavated round house.

*Comment* (TG): previous sample from this building yielded a date of 2780 ± 80 BP (HAR-4800). Charcoal from this and other postholes antedates construction of building, perhaps by several centuries and should be assoc with one or more episodes of forest clearance and evidence for cereal cultivation, including emmer wheat and six-row barley (Davies & Turner 1979).

**HAR-8185. HAL-25** **2710 ± 70**  
 $\delta^{13}C = -26.6\%$

Identified as *Alnus* sp, AML 8650180, from small pit, Context 25, containing burned stones, carbonized plant material and some burned bone.

*Comment* (TG): no datable artifacts were in pit which could be rubbish deposit or cremation. Stratigraphic relationship between pit and occupation of building could not be determined in excavation.

*General Comment:*  $^{14}C$  dates indicate more complicated sequence of activity than could have been deduced from either structural or stratigraphic evidence. Results for two postholes, HAR-8184 and -4800, and pits, HAR- 8183 and -8185, imply that site witnessed more than one phase of Bronze Age agriculture before construction of timber building. This accords well with palynology and  $^{14}C$  dating at nearby site at Steng Moss.

#### Hemington Fields series

Wood from Hemington Fields (Salisbury 1981), Donington, Leicestershire (52°52'1" N, 1°19'13" W, NGR SK 45753020). Coll March and subm April 1986 by C R Salisbury.

**HAR-8223. PL6BRW86**

**5240 ± 80**  
 $\delta^{13}C = -28.6\%$

Ash, AML 868088, from bed of ancient course of river Trent which was abandoned and rapidly filled with gravel.

*Comment (CRS):* this sample was thought to be assoc with Norman mill dam or late Bronze Age post alignment. Its Neolithic date was a surprise. Sample may have come from a clast of peat derived from another abandoned channel and redeposited here.

**HAR-8224. PL1WAT85**

**910 ± 70**  
 $\delta^{13}C = -27.6\%$

Hazel, average 11 rings, AML 868087, from wattle panel in floodplain gravel below water table, probably part of fish weir.

*Comment (CRS):* main structure is Norman mill dam made of squared oak posts and timbers. Between double row of posts is parallel row of small birch posts with bark, two of which were dated to 800 cal BC. Result confirms that weir is assoc with Norman dam, dated dendrochronologically to AD 1140 and allows E Midland master curve to be extended back 50 yr more.

**HAR-8256. AP86-1**

**700 ± 40**  
 $\delta^{13}C = -25.4\%$

Wood, identified as oak (*Quercus* sp), AML 8650143, Abington Pigotts, Downhall Gatehouse (52°4'33" N, 0°5'49" W, NGR TL304437). Sample from West Gable tie beam from late Medieval gatehouse (14th or 15th century). Coll and subm Sept 1986 by D Sherlock.

*Comment (DS):* beam was taken down ca 1980 when new tie beam was inserted.

**Tintagel Castle series**

From Tintagel Castle, Lower Ward, Tintagel, Cornwall (50°40'2" N, 4°45'27" W, NGR SX 05158897). Coll Jan and subm May 1986 by S Hartgroves, Cornwall Archaeol Unit.

**HAR-8273. TCD/43**

**2740 ± 100**

Charcoal and soil, AML 8650069, from Stakehole 43.

$\delta^{13}C = -27.8\%$

**HAR-8276. TCD253**

**2110 ± 120**

Charcoal, burned wood and soil, AML 8650068, from Layer D 25.

$\delta^{13}C = -29.0\%$

**HAR-8277. TCD/7**

**1850 ± 80**

Charcoal and soil, AML 8650070, from Stakehole 71.

$\delta^{13}C = -27.9\%$

**HAR-8278. TCD/102**

**1850 ± 70**

Charcoal and soil, AML 8650071, from Stakehole 102.

$\delta^{13}C = -27.5\%$

*General Comment (SH):* these results help provide upper and lower limits to use of imported Mediterranean pottery and date newly discovered timber phase.

**Hazleton Long Cairn series**

Antlers, identified as red deer, from Hazleton North Long Cairn, near Northleach, Hazleton parish, Glos (51°52'5" N, 1°53'38" W, NGR SP073189) (Saville 1984).

**HAR-8349. 13926** **4830 ± 60**  
 $\delta^{13}C = -23.5\text{‰}$

AML 8650031, from Context 463, incorporated in early phase of cairn's construction, from base of cairn infill adjacent to S and N. Coll July 1982 by A Hearne and A Saville and subm Aug 1986 by A Saville, Cheltenham Mus and Art Gallery.

**HAR-8350. 3129** **4950 ± 60**  
 $\delta^{13}C = -23.4$

AML 8650032, from Context 85, primary infill of N quarry flanking long cairn, 160mm above quarry floor. Coll Nov 1980 and subm Aug 1986 by A Saville.

*Comment (AS):* dated for quarrying activity in N quarry. Antler is part of discarded tool used in quarrying limestone for cairn.

**St Oswald's Priory series**

Human bone samples from St Oswald's Priory, Gloucester (51°52'8" N, 2°14'49" W, NGR SO 830190). Coll Aug 1978 and subm April 1986 by C M Heighway.

**HAR-8357. 4175B507** **1070 ± 70**  
 $\delta^{13}C = -21.0\text{‰}$

AML 8650017, above B518 in stack of six Saxon burials.

*Comment (CMH):* second earliest sample in sequence of 6 burials, is subsequent to B518 (HAR-8358).

**HAR-8358. 4175B518** **1100 ± 70**  
 $\delta^{13}C = -21.0\text{‰}$

AML 8650016, from second lowest of stack of six Saxon burials.

*Comment (CMH):* earliest sample in sequence of 6 burials, is under B507 (HAR-8357).

*General Comment (CMH):* samples date foundation of church, which is pre-1086 on architectural grounds and which is said by William of Malmesbury to date from time of Alfred. Burials began when church was built. The two samples appear to confirm late 9th century date for church's construction (Heighway 1980; 1984).

**HAR-8365. DMG83196** **3350 ± 70**  
 $\delta^{13}C = -29.3\text{‰}$

Soil, waterlogged organic deposit (wood, seeds etc), AML 865022, Durham Milburnegate, Durham City, (54°46'40" N, 1°34'39" W, NGR NZ 27184264). Sample from organic deposit, sealed by 13th century occupation, at lowest level on site and overlying natural woodland. Coll July 1983 and subm March 1986 by M van der Veen, Archaeol Dept, Univ Durham.

*Comment (MvdV):* result indicates truncated soil profile, unrecognized during excavation.

Woodland represented in sample must be of early prehistoric date (van der Veen 1985) and therefore has no bearing on Medieval Durham.

### Buckskin II series

**HAR-8370. 1BS7**

**3590 ± 100**  
 $\delta^{13}C = -27.1\%$

Charcoal, AML 8650023, from F7 posthole beneath core of mound at Buckskin site I (Bell Barrow), Basingstoke, Hampshire (50°18'40" N, 5°21'55" W, NGR SW 60435118). Coll 1967-8 by B Applin and subm by M Morris, Winchester Archaeol Office.

*Comment (MM):* series of pits, postholes and stakeholes, survived in central area of mound. Results help date mound construction. There is no other dating evidence from these features.

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Holocene ages, Punta Hermengo (38°18' S, 57°52' W), Miramar, Buenos Aires Prov. Samples coll and subm 1981 by F Fidalgo and J Figini, FCNyM.

**LP-86. Sample I** **3400 ± 110**

Carbonate powder dispersed into sandy-silt sediment from exposed profile below Puesto Berrondo buried soil.

*Comment:* no pretreatment.

**LP-87. Sample II** **6680 ± 140**

Shells (*Litoridina parchappei*) from exposed profile underlying Puesto Berrondo buried soil and Puesto Callejon Viejo paleosol.

*Comment:* no acid pretreatment.

*General Comment:* ages agree with proposed paleontologic-geologic sequence by Fidalgo and Tonni (1983) for upper continental sediments.

#### Arroyo Seco series

Pedogenic carbonate from stratigraphic sequence at archaeol Site 2 (38°21'38"S, 60°14'39" W), Arroyo Seco, Tres Arroyos, Buenos Aires Prov. Coll April 1981 by F Fidalgo and LATYR personnel.

**LP-92. Sample I** **1890 ± 80**

Pedogenic carbonate from silty-sand sediment, 6% CaCO<sub>3</sub> conc, 0.7m depth.

*Comment:* no pretreatment. Age is younger than expected probably due to contamination by young carbon dissolved in meteoric waters that penetrated profile.

**LP-93. Sample II** **5740 ± 120**

Pedogenic carbonate from silt with sand and clay sediment, 16% CaCO<sub>3</sub> conc, 0.75m depth.

*Comment:* no pretreatment.

**LP-94. Sample III** **5700 ± 120**

Pedogenic carbonate from silt with clay and sand sediment, 14% CaCO<sub>3</sub> conc, 0.85m depth.

*Comment:* no pretreatment.

*General Comment:* concordance between LP-93 and -94 ages shows that this horizon corresponds to same weathering process. Chronologic sequence agrees with stratigraphic position of samples and other dates from same site (LP-53, 8390 ± 240 (Figini *et al* 1984: 132)).

#### Teatro Argentino series

Continental sediments named "Sedimentos Pampeanos" from ca 30m profile of Teatro Argentino building, La Plata city (34°54'36" S, 57°56'03" W), Buenos Aires Prov. Coll May 1981 by F Fidalgo and LATYR personnel.

**LP-95. Sample I 13,160 ± 230**

Pedogenic carbonate from 2.5m depth in sandy-clay silt sediment, 28% CaCO<sub>3</sub> by weight.

**LP-96a. Sample II 15,300 ± 260**

Pedogenic carbonate from 5m depth in the same sediment as LP-95, 56% CaCO<sub>3</sub> by weight.

**LP-96b. 14,570 ± 280**

Duplicate of LP-96a.

**LP-98. Sample III >37,000**

Pedogenic carbonate from 8.5m below discontinuous contact corresponding to one incipient K horizon. CaCO<sub>3</sub> from sandy-silt clay sediment, 10% by weight.

**LP-99. Sample IV 32,700 ± 1400**

Pedogenic carbonate from 9.5m depth below LP-98 in same sediment, 18% CaCO<sub>3</sub> by weight.

*Comment:* age is pooled mean of two determinations: LP-99a: 32,900 ± 1900 and LP-99b: 32,600 ± 2200.

*General Comment:* <sup>14</sup>C ages agree with relative age of lithostratigraphic units; also they show more than one pedogenic cycle. LP-99 is probably contaminated by modern carbon; thus, age would be >32,700 yr. Age sediments cannot be established through palaeontologic or geologic evidence; Late Pleistocene age is suggested.

### Las Escobas III series

Mollusk shells from Holocene marine coastal deposit belonging to Cerro de la Gloria member of Las Escobas Fm (Fidalgo, De Francesco & Colado 1973) at exposed profile in Rincon de Lopez (35°46'07" S, 57°24'30" W), Castelli, Buenos Aires Prov. Coll 1980-1982 by F Fidalgo and LATYR personnel. Shells identified by D Fernandez, FCNyM; calcite/aronite x-ray diffraction analyses by M Iñiguez Rodriguez, FCNyM.

**LP-111. Sample I, Site 1 3150 ± 70**

Shells (*Macra isabelleana*) ca 1.9m depth below surface.

*Comment:* outer 20% of shells removed by acid pretreatment; remaining portion consisting of 4.9% calcite, 95.1% aragonite, was dated.

**LP-112A. Sample II, Site 1 3150 ± 90**

**LP-112B. Sample II, Site 1 3050 ± 90**

Shell (*Adelomedon brasiliiana*) ca 1.9m depth below surface, assoc with LP-111.

*Comment:* LP-112A was outer 20% of shell removed by acid pretreatment and dated; remaining portion, -112B, consisting of 0.7% calcite and 98.3% aragonite, was dated.

<b>LP-114A.</b>	<b>Sample III, Site 1</b>	<b>6460 ± 110</b>
<b>LP-114B.</b>	<b>Sample III, Site 1</b>	<b>7220 ± 100</b>

Shell (*Adelomedon brasiliiana*) ca 1.9m depth below surface, assoc with LP-111 and -112.

*Comment:* LP-114A was outer 20% of shell removed by acid pretreatment and dated; remaining portion, -114B, consisting of 100% aragonite, was dated.

<b>LP-116.</b>	<b>Sample IV, Site 2</b>	<b>3490 ± 80</b>
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Shells (*Maetra isabelleana*) ca 2m below surface, 3.25m from Site 1.

*Comment:* outer 20% of shells removed by acid pretreatment and discarded; inner fraction, consisting of 2.9% calcite and 97.1% aragonite, was dated.

<b>LP-117A.</b>	<b>Sample V, Site 2</b>	<b>4320 ± 80</b>
<b>LP-117B.</b>	<b>Sample V, Site 2</b>	<b>3760 ± 60</b>

Shell (*Adelomedon brasiliiana*) ca 2m below surface, assoc with LP-116.

*Comment:* LP-117A was outer 20% of shell removed by acid pretreatment and dated; remaining portion, -117B, consisting of 1% calcite and 99% aragonite, was dated.

<b>LP-119A.</b>	<b>Sample VI, Site 2</b>	<b>4760 ± 110</b>
<b>LP-119B.</b>	<b>Sample VI, Site 2</b>	<b>4910 ± 110</b>

Shell (*Adelomedon brasiliiana*) ca 2m below surface, assoc with LP-116 and -117.

*Comment:* LP-119A was outer 20% of shell removed by acid pretreatment and dated; remaining portion, -119B, consisting of 8.6 calcite and 91.4% aragonite, was dated.

<b>LP-121A.</b>	<b>Sample VII, Site 2</b>	<b>3460 ± 70</b>
<b>LP-121B.</b>	<b>Sample VII, Site 2</b>	<b>3330 ± 50</b>

Shell (*Adelomedon brasiliiana*) ca 2m below surface, assoc with LP-116, -117 and -119.

*Comment:* LP-121A was outer 20% of shell removed by acid pretreatment and dated; remaining portion, -121B, consisting of 8% calcite and 92% aragonite, was dated.

<b>LP-124A.</b>	<b>Sample VIII, Site 2</b>	<b>6850 ± 90</b>
<b>LP-124B.</b>	<b>Sample VIII, Site 2</b>	<b>6340 ± 90</b>

Shell (*Adelomedon brasiliiana*) ca 2m below surface, assoc with LP-116, -117, -119 and -121.

*Comment:* LP-124A was outer 20% of shell removed by acid pretreatment and dated; remaining portion, -124B, consisting of 7.7% calcite and 92.3% aragonite, was dated.

*General Comment:* shells died at different ages and were redeposited, which is consistent with nature of deposit.

#### Las Escobas IV series

Mollusk shells belonging to Cerro de La Gloria member of Las Escobas Fm, from exposed profile of Canal 15 (35°58'21" S, 57°29'16" W). Samples were extracted in vertical sequence; identified by D Fernandez; calcite/aragonite x-ray diffraction analyses by M Iñiguez Rodriguez.

- LP-110. Sample 14** **4510 ± 110**  
Shells (*Mactra isabelleana*) from ca 0.60m depth; outer 20% of shell removed by acid; remaining portion consisting of 25% calcite and 75% aragonite, was dated.
- LP-147. Sample 14** **4220 ± 110**  
Shells (*Mactra isabelleana*) from ca 0.60m depth; outer 35% of shell removed by acid pretreatment and dated, remaining portion was discarded; calcite was not determined.
- LP-109. Sample 13** **4550 ± 100**  
Shells (*Mactra isabelleana*) from ca 1m depth; outer 20% of shell removed by acid; remaining portion consisting of 30% calcite and 70% aragonite, was dated.
- LP-154. Sample 13** **4610 ± 90**  
Shells (*Mactra isabelleana*) from ca 1m depth; outer 35% of shell removed by acid pretreatment and dated, inner portion was discarded; calcite was not determined.
- LP-108. Sample 12** **4800 ± 90**  
Shells (*Mactra isabelleana*) from ca 1.60m depth; outer 20% of shell removed by acid; remaining portion consisting of 5% calcite and 95% aragonite, was dated.
- LP-158. Sample 12** **4680 ± 70**  
Shells (*Mactra isabelleana*) from ca 1.60m depth; outer 35% of shell removed by acid pretreatment and dated, remaining portion was discarded; calcite was not determined.
- LP-107. Sample 11** **4440 ± 110**  
Shells (*Mactra isabelleana*) from ca 2.40m depth; outer 20% of shell removed by acid; remaining portion consisting of 100% aragonite, was dated.
- General Comment:* Samples 12, 13 and 14 were divided into two portions for dating inner and outer fractions.
- LP-113. Río Sauce Grande-La Toma** **1150 ± 70**  
Wood (*Salix humboldtiana*) identified by J Bonisegna and R Villalba, IANIGLIA, from outcrop, 6m deep from top of ravine, Río Sauce Grande-La Toma (38°15' S, 61°45' W), Buenos Aires Prov. Coll and subm Feb 1984 by J Rabassa.
- Comment (JR):* Lujanese mammalian age estimated by correlation with strata containing extinct fauna. Other portion of same sample was dated at 1570 ± 45 (SI-6848; Stuckenrath, pers commun).
- Cueva Tixi series**  
Carbonate layers in stratigraphic sequence of Tixi cave (37°58'30" S, 58°04'04" W), containing palaeontologic and archaeological debris, in slope of La Vigilancia range, General Alvarado, Buenos Aires Prov. Coll Dec 1983 by F Fidalgo and LATYR personnel.

**LP-140. Sample I** **1220 ± 70**

Carbonate from layer, 0.23m thick, at top of stratigraphic sequence.

*Comment:* no pretreatment was made.

**LP-139. Sample II** **1730 ± 80**

Carbonate from layer, 0.05m thick, 0.38m depth below LP-140.

*Comment:* no pretreatment was made.

*General Comment:* these ages agree with stratigraphic sequence and relative chronology based on faunal remains.

#### Valle del Rio Sauce Grande series

Snail shells from Upper Pleistocene and Holocene continental deposits corresponding to Agua Blanca Fm and Saavedra Fm. Coll and subm Feb 1985 by J Rabassa. Mollusk shells identified by D Fernandez; x-ray diffraction analyses by M Iñiguez Rodriguez.

**LP-115. Balneario Saldungaray SG 96** **32,300 ± 1800**

Snail shells (*Plagiodontes patagonicus*) dispersed through middle sandy member of Agua Blanca Fm at 210m above msl (38°12' S, 61°46' W), Saldungaray, Buenos Aires Prov.

*Comment:* inner fraction (70%) was used with 2% calcite and 98% aragonite.

**LP-118. Camino Saldungaray RP 51** **9780 ± 140**

Snail shells (*Plagiodontes patagonicus*) dispersed through piedmont deposit of superior member of La Toma Fm at 180m above msl (38°14' S, 61°43' W), Ruta Provincial 51, Saldungaray.

*Comment:* inner fraction was used with 10% calcite and 90% aragonite.

**LP-120. Lartigau** **113.9 ± 0.7 pMC**

Snail shells (*Plagiodontes patagonicus*) coll alive on shrubs growing on outcrop of La Toma Fm at 180m above msl (38°23' S, 61°38' W) Lartigau, Buenos Aires Prov.

*Comment:* flesh was separated from shell in boiling water; inner shell fraction (90%) was used.

*General Comment:* snail shells (*Plagiodontes patagonicus* and *Austroborus lutescens*) from upper member of Saavedra Fm were dated at 5500 ± 200 and 3890 ± 110 (SI-6450A and SI-6450B; Stuckenrath, pers commun). LP-118 and both SI ages agree with Holocene age of these stratigraphic units. LP-115 confirms Upper Pleistocene age of unit, which had been attributed to Lujanese mammalian age. LP-120 shows current depletion of <sup>14</sup>C atmospheric level marked by snails.

#### La Plata Eubalena series

Mandibular branch (*Eubalena australis*) from Holocene marine sediments corresponding to Las Escobas Fm (34°53'39" S, 57°56'47" W) Ensenada, Buenos Aires Prov. Coll and subm Aug 1982 by F Fidalgo. Taxonomic determination was made by E Tonni, FCNyM.

<b>LP-141a.</b>	<b>Bone grinding &lt;0.17mm</b>	<b>4600 ± 100</b>
<b>LP-141b.</b>		<b>5690 ± 250</b>
<b>LP-141c.</b>		<b>4870 ± 160</b>

*Comment:* each sample was pretreated according to Longin (1971) in 1M HCL for 15 min.

<b>LP-141d.</b>	<b>Bone grinding &lt;2.0mm</b>	<b>4420 ± 80</b>
<b>LP-141e.</b>		<b>3880 ± 90</b>
<b>LP-141f.</b>		<b>3750 ± 80</b>
<b>LP-141g.</b>		<b>3960 ± 100</b>
<b>LP-141h.</b>		<b>4040 ± 90</b>
<b>LP-141i.</b>		<b>4070 ± 90</b>

*Comment:* each sample was pretreated in 1M HCL for 24 hr in vacuum.

*General Comment:* in this study, we have introduced variations in pretreatment (time and particle-size) in order to recover the maximum protein content and assure the total dissolution of inorganic matrix. We did not obtain a complete acid dissolution of inorganic matrix in LP-141a, -141b and -141c. We obtained a complete acid dissolution of bone and an increase of protein flocculate in LP-141d, -141e, -141f, -141g, -141h and -141i. In all cases, collagen was extracted according to Longin (1971) in HCL solution pH 2-3 at 80°C for 24 hr and used for dating. Several determinations were made to evaluate variability of dates.

<b>LP-141j</b>	<b>Total bone acidification</b>	<b>1060 ± 90</b>
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*Comment:* CO<sub>2</sub> from acid evolution of bone sample. This result shows trend of inorganic contamination.

### Baradero series

Bone (*Balaenoptera cf physalus*) from estuarine sediments corresponding to Las Escobas Fm near Baradero city (33°50' S, 59°30' W) Buenos Aires Prov, from 0.30-0.50m depth. Coll July 1986 by A Figini and F Fidalgo, identified by E Tonni.

<b>LP-153a.</b>		<b>5630 ± 100</b>
Collagen.		

<b>LP-153b.</b>		<b>5420 ± 110</b>
Duplicate.		

*Comment:* both samples were pretreated in 1M HCL for 24 hr in vacuum; collagen was extracted according to Longin (1971). Pooled mean was reported as LP-153: 5540 ± 80.

<b>LP-153c.</b>		<b>2710 ± 110</b>
CO <sub>2</sub> from bone acidification.		

*Comment:* this age shows trend of inorganic contamination.

### Lobería series

Bone sample from continental deposit of Late Pleistocene and Holocene ages, corresponding



to La Postrera Fm, Lobería (38°09' S, 58°48' W), Buenos Aires Prov. Coll, identified and subm Aug 1986 by E Tonni.

**LP-152a.** **10,590 ± 120**

Collagen from dermal ossicles of *Glossotherium (Pseudolestodon) myloides*.

**LP-152b.** **10,860 ± 130**

Duplicate.

*Comment:* pretreatment and collagen extraction of both samples equal to LP-153a and -153b. Pooled mean reported was LP-152: 10,710 ± 90.

**LP-152c.** **4150 ± 90**

CO<sub>2</sub> from bone acidification.

*Comment:* this age shows trend of inorganic contamination.

#### ARCHAEOLOGIC SAMPLES

##### *Argentina*

**LP-85. CPV/96 Pichileufú** **2530 ± 90**

Charcoal from occupational floor at 0.68-0.70m depth, level VIII, Río Pichileufú Cave (41°04' S, 70°52' W), Pilcaniyeu, Río Negro Prov. Coll and subm March 1981 by R Ceballos, Fac Humanidades, Univ Nac Rosario (UNR).

*Comments (RC):* corresponds to postglacial guanaco hunters of Northern Patagonia. (Myriam Tarragó (MT)): provides *ante quem* date for wall engravings which were covered by Levels I-XI. Such engravings are supposedly related to the cave's most ancient inhabitants. See Ceballos and Peronja (1983) for discussion.

**LP-88. Fortin Marias II ó Fortin Necochea, Locus 2** **6010 ± 400**

Collagen from guanaco bone fragments at 0.9-1.0 below datum, Quad C21, Fortin Necochea (37°23'49" S, 61°08'15" W), near La Madrid city, Buenos Aires Prov. Coll by M Silveira and E Crivelli and subm Jun 1981 by A Sanguinetti, Inst Antrop, Fac Filosofía y Letras, Univ Nac Buenos Aires, (UBA).

*Comments (MS-EC):* dates early (but not first) occupation of an open-air stratified site. (MT): consistent with CSIC-593: 3630 ± 60. See Crivelli, Eugenio and Silveira (1987-1988) for discussion.

**LP-89. Guayra Azul I** **1100 ± 60**

Charcoal at 0.26m depth, Layer 2, Sec 3, Alero Guayra Azul I (22°57'56" S, 66°15'16" W), Cochinoqa, Jujuy Prov. Coll by A Fernandez Distel and subm Jun 1981 by M Califano, Centro Argentino Etnol Am, CAEA.

*Comments (MC):* evaluation of hypothesis about aboriginal relations with San Pedro de Atacama, Chile. (MT): corresponds to Late Formative period of Quebrada de Humahuaca and Puna region's

chronologic sequence. It would be contemporary to Tiahuanaco Expansive period of both Atacama region and Bolivian Highlands.

**LP-91. Abra de la Ventana** **6230 ± 90**

Charcoal at 0.4-0.7m depth, Cueva del Abra (38°05' S, 62° W) Sierra de la Ventana region, Buenos Aires Prov. Coll and subm June 1979 by A Castro, Fac Ciencias Nat y Museo (FCNyM), Univ Nac La Plata (UNLP).

*Comment* (AC): this is the first date for lithic material that corresponds to Tandiliense industry in this cave, and represents an early occupation of Pampa Bonaerense.

**LP-90. Los Matos II** **2670 ± 70**

Charcoal from archaeological refuse at 0-0.40m depth, Test Pit B, Los Matos II, Quebrada de Los Matos (25°07' S, 64°52' W), Anta Dept, Salta Prov. Coll and subm Oct 1983 by A Fernandez, FCNyM.

*Comments* (AF): charcoal specks dispersed throughout deposit. Date should determine chronologic span of La Candelaria culture at AD 400-700. (MT): date was rejected because deposits were disturbed by bulldozer's action and date did not correspond to what was expected.

**Inca Cueva series**

Samples from Layer 2, Inca Cueva 4 (IC<sub>c</sub>4), Quebrada de Inca Cueva (23° S, 65°27' W), Humahuaca Dept, Jujuy Prov. Coll and subm Nov 1983 by C Aschero, Inst Nac Antrop, Buenos Aires.

**LP-102. M-2** **9650 ± 110**

Charcoal at 0.50-0.53m depth, Quad L3a.

**LP-137. M-1** **10,620 ± 140**

Stem and leaves (*Hypsocharis* sp) at 0.45-0.52m depth, Quad M4a.

*Comment*: sample was boiled in 2% HCL.

*General Comments* (CA): date should determine relative synchrony in presumed occupation level. Samples correspond to different quadrants and deposition episodes in refuse area. (MT): LP-102 and -137 respectively, date medium and lower strata. Both samples agree with AC-564: 9900 ± 200 and CSIC-4980: 9230 ± 70 from habitation area. The four dates correspond to archaic hunter-gatherer occupation level in rock-painting shelter. Layer 2 includes several features such as subcircular room floor, postholes and five storage pits dug into sandy substrate. Stemless triangular dart points are similar to those recovered at Huachichocana III-E3 (Tumbaya Dept), La Cueva (Yavi Dept) both in Jujuy Prov and Tuina in northern Chile. See Aschero (1980) for discussion.

**LP-104. Cabo San Pablo 1** **290 ± 70**

Charcoal from shell midden at 0.25-0.28m depth, Cabo San Pablo region, Tierra del Fuego. Coll and subm Nov 1983 by L Borrero, Inst Ciencias Antrop, UBA.

*Comment* (LB): dates cultural remains assoc with Selk'nam technology. Should provide chronologic framework for human occupation of Cabo San Pablo area and its inter-site relations.

**LP-105. Antumpa R II G-5** **1360 ± 70**

Bone fragments (mostly *Lama* sp) from circular dwelling at Antumpa (22°59' S, 65°21' W), Quebrada de Humahuaca, Jujuy Prov. Coll and subm Aug 1982 by S Renard de Coquet and M Hernandez Llosas, Inst Antrop Hist Hispanoamericana, Buenos Aires.

*Comments* (SRC & MHL): date should provide chronologic framework for occupation of circular dwelling in agricultural village of Quebrada de Humahuaca area. (MT): this is one of first dates for this area which places site towards end of Early Formative period of northwestern Argentina. See Hernandez Llosas, Renard and Podestá (1983-1985).

**LP-136. Los Toldos M3 85** **4850 ± 90**

Charcoal fragments from 0.35-0.45m depth, in topmost Layer 4 and beneath ash layer, Cave 3, Los Toldos (47°28' S, 68°50' W), Santa Cruz Prov. Coll and subm March 1985 by A Cardich, FCNyM.

*Comments* (AC): date should provide chronology of Casapedrense occupation in this cave. (MT): confirms relationship between end of Casapedrense lithic industry occupation and cave's volcanic ash layer.

**LP-142. Pueblo Viejo de la Cueva** **1180 ± 50**

Charcoal from hearth at 0.60-1.0m depth, Level III-V, Sec 1, Quad A, Pueblo Viejo de la Cueva (22°50' S, 65° 22' W), Quebrada de Humahuaca, Jujuy Prov. Coll and subm Jan 1984 by S Basilico de Valter and R Brito, Secy Cult Educ, Jujuy Prov.

*Comments* (MT): assoc with abundant domestic ware and La Isla ceramic style together with faunal remains corresponding to Middle and Late Formative period of Quebrada de Humahuaca region.

**LP-144. Cueva Trafal III** **4120 ± 80**

Charcoal from hearth at 3.65-3.87m depth, Layer 17, Trafal III (also known as Los Maitenes Cave) (40°42'15" S, 71°09' W), Valle Encantado, Los Lagos, Neuquén Prov. Coll and subm April 1985 by D Curzio, Prog Estudios Prehist, CONICET-UBA.

*Comment* (DC): sample corresponds to first preceramic occupation of cave assoc with some flakes.

**Alero Los Cipreses series**

Samples from archaeological site Alero Los Cipreses (40°38'45" S, 71°19' W), Trafal Lake, Neuquén Prov. Coll and subm March 1985 by M Silveira, Inst Antropol, UBA.

**LP-145. PTA-6 no. 9** **1510 ± 90**

Charcoal from hearth at 0.45-0.5m depth, Quad 3.

**LP-159. PTA-6 no. 12** **3490 ± 80**

Charcoal from hearth at 0.70-0.75m depth, Layer 4, Quad 6.

*General Comment* (MS): date should determine chronologic framework for ceramic and non-ceramic components of site.

**Casa Piedra de Ortega series**

Charcoal from Casa Piedra de Ortega, Paraje Corralito (40°44' S, 70°42' W), Pilcaniyeu, Río Negro Prov. Coll and subm March 1985 by E Crivelli, Fac Filosofía y Letras, UBA.

**LP-146. CPO 10/85** **2840 ± 80**

Charcoal from hearth at 1.43-1.48m below datum, Layer i, Quad G3.

*Comment* (EC): dates first occupation of cave and gives *terminus ante quem* for engravings in bedrock.

**LP-168. CPO 5/86** **2000 ± 90**

Charcoal at 1.25-1.29m below datum, Layer e2, Quads G1 and H1.

*Comment* (EC): dates aceramic phase of northern Patagoniense lithic industry.

*General Comment* (EC): both dates agree with cave's stratigraphy as well as with other dates from same site (all unpub): AC-951: 2710 ± 100 from Layer H; AC-936: 1440 ± 80 from Layer 3; LP-191: 280 ± 50 from Layer e2.

**LP-156. Talampaya** **1830 ± 60**

Wooden artifact (*Larrea* sp) identified by L Berridi and R Mamblona, Esc Sup Bosques UNLP, from Talampaya site (29°46'05" S, 67°46'07" W) Independencia, La Rioja Prov. Coll and subm Sept 1985 by M Gonaldi, Inst Antrop, Univ Prov La Rioja.

*Comment* (MT): from man-made lookout dug into rocky scarp assoc with other wooden objects, basketry, leather, wool, feathered sticks, maize and a domestic-ware sherd, which were lying on a bed of straw and branches, covered by a thick layer of pebbles. Date is related to Early Formative period of Valliserrana region of northwestern Argentina.

**LP-157. Playa Grande no. 9** **1800 ± 80**

Charcoal from shell midden at 0.10m depth, Playa Grande (48°58' S, 67°27' W) Santa Cruz Prov. Coll and subm March 1986 by A Cardich, FCNyM, UNLP.

*Comment* (MT): should date Santa Cruz's coastal occupation.

**LP-160. Punta Bustamante** **3200 ± 80**

Charcoal at 0.35m depth, 70-80m amsl at 1500m off shoreline, from Rudd I site (51°33'30" S, 68°58'40" W), Punta Bustamante, Guer Aike, Santa Cruz Prov. Coll and subm Feb 1985 by E Mansur, Centro Austral Investigaciones Científicas, CADIC.

**LP-165. La Huerta** **1150 ± 80**

Charcoal from refuse area at 1.45-1.78m depth, Quad C1, Layer XV-XVI, La Huerta (23°30' S, 65°20' W), Quebrada de Humahuaca, Jujuy Prov. Coll and subm May 1986 by R Raffino, FCNyM, UNLP.

*Comments* (RR): this date shows Inka-Humahuaca cultural contact in NW Argentina. (MT): date corresponds to refuse area in center of La Huerta town; related to pre-Inka phase of site. Upper layers show cultural contact between Humahuaca and Inka cultures and European objects.

**LP-166. Los Flamencos I** **3100 ± 110**

Bone collagen (*Lama* sp) from Los Flamencos I (37°40' S, 62°25' W), Campo Fernandez, Saavedra, Buenos Aires Prov. Coll and subm May 1986 by A Austral, FCNyM, UNLP.

*Comment* (MT): sample from upper layers of archaeological stratigraphy of non-ceramic component. Date should provide chronologic framework for pampean pottery, resulting in date somewhat later than expected (4000 BP).

**LP-167. Lago San Roque** **3500 ± 110**

Human bone collagen at 0.70m depth, Lago San Roque Beach (31°22' S, 64°33' W), Carlos Paz city, Cordoba Prov. Coll and subm Jan 1987 by Poder Judicial de Cordoba (Cordoba Dept Justice).

*Comment*: data requested for judicial investigation.

**LP-169. Susques** **400 ± 100**

Wood (*Trochocereus* sp) from roof of house, Susques (23°16' S, 66°16' W), Jujuy Prov. Coll, identified and subm May 1986 by A Fernandez Distel.

*Comment* (AFD): date should provide chronologic framework for architectural structures related to Late Regional Developments period of Puna de Atacama region.

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## UNIVERSITY OF WISCONSIN RADIOCARBON DATES XXVI

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Procedures and equipment used in the University of Wisconsin laboratory have been described in previous date lists (Bender, Bryson & Baerreis 1965; Steventon & Kutzbach 1986). Except as otherwise indicated, wood, charcoal and peat samples are pretreated with dilute NaOH- $\text{Na}_4\text{P}_2\text{O}_7$  and dilute  $\text{H}_3\text{PO}_4$  before conversion to counting gas methane; when noted, marls and lake cores are treated with acid only. Very calcareous materials are treated with HCL instead of  $\text{H}_3\text{PO}_4$ .

The dates reported have been calculated using 5568 yr as the half-life of  $^{14}\text{C}$ . The standard deviation quoted includes only  $1\sigma$  of the counting statistics of background, sample and standard counts. Background methane is prepared from anthracite; standard methane from NBS oxalic acid. The activities of the dated samples for which  $\delta^{13}\text{C}$  values are listed have been corrected to correspond to a  $\delta^{13}\text{C}$  value of  $-25\text{‰}$ ; the activity of the standard methane has been corrected to  $-25\text{‰}$ .

Sample descriptions are based on information supplied by those who submitted samples.

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### ARCHAEOLOGIC SAMPLES

#### *United States*

#### *Iowa*

#### **Turkey River Mound Group (13CT1) series**

Wood charcoal coll 1964 from Turkey River Mounds, Clayton Co (42°43'N, 91°02'W) by M McKusick and subm by W Green, Univ Iowa (Green 1988a; McKusick 1964).

#### **WIS-2049.**

**2550 ± 60**  
 $\delta^{13}\text{C} = -26.9\text{‰}$

Sample from Burial 4, Mound 37, an extended adult who was decapitated *post mortem* or *perimortem*. Red Ocher was directly associated.

<sup>1</sup>Raymond L Steventon retired in 1989 as Director of the University of Wisconsin Radiocarbon Laboratory. Dr Christine Prior assumed responsibility of the Radiocarbon Laboratory December 1, 1989.

**WIS-2050.****1490 ± 50** $\delta^{13}C = -22.9\text{‰}$ 

Sample from Burial 1 and 2, Mound 38 (cremated skulls), probably part of same mortuary program as articulated burials 3-11 located at base of mound in association with Red Ocher grave goods.

**WIS-2051. Archaeological site 13CT228****2580 ± 60** $\delta^{13}C = -25.0\text{‰}$ 

Wood charcoal coll Nov 1987 from site in Clayton Co (42°44'N, 91°08'W) by W Green and J Cordell and subm by W Green. Dates a Durst phase occupation situated within a Holocene terrace along Turkey River, NE Iowa. First date for non-rockshelter Late Archaic occupation in region.

**WIS-2069. Archaeological site 13TM173****9550 ± 100**

Soil horizon from site in Tama Co (42°57'N, 92°34'W) coll by D Richardson and J D Anderson and subm by W Green. Dates paleosol in alluvial fan deposit in which microdebitage was found. Underlain by main-valley flood deposits of Iowa River.

**WIS-2076. Archaeological site 13ML176****1200 ± 70** $\delta^{13}C = -25.7\text{‰}$ 

Red elm (*Ulmus rubra*) charcoal from site 13ML176, Mills Co (41°07'N, 95°47'W), coll June 1984 by S Schermer and subm by W Green. Sample from outer rings of a central support post (Feature 12) of a Nebraska phase (Glenwood locality) earthlodge (Green 1988b).

*Wisconsin***Camp Indianola site (47Da533) series**

Wood charcoal coll May-July 1986 from Camp Indianola, Dane Co (43°07'N, 89°26'W) by S L Stand, S K Salzsider, M L Propson and J A Clark, and subm by V Dirst, Wisconsin Dept Nat Resources, Madison.

**WIS-1993.****1840 ± 60** $\delta^{13}C = -26.6\text{‰}$ 

Sample from Feature 7, a Middle Woodland trash pit containing Kegonsa Stamped sherds, chert flakes and fire-cracked rock.

**WIS-1994.****Modern** $\delta^{13}C = -26.7\text{‰}$ 

Sample from hearth believed to be associated with Kegonsa Stamped ceramics in adjacent living space.

**WIS-1995.****1420 ± 70** $\delta^{13}C = -26.3\text{‰}$ 

Sample from Feature P. Dates Late Woodland occupation believed contemporary with stockade.

**Ot site (47Lc262) series**

Charcoal coll 1986-1987 from Ot site, La Crosse Co (43°56'30"N, 91°15'30"W) by D M Stemper, N Meinholtz and J A O'Gorman and subm by J T Penman, State Hist Soc, Madison. Ot is a small habitation site with adjacent cemetery probably serving as burial ground for inhabitants of Ot and Tremaine (47Lc95) village (Broihahn, Penman & Rusch 1987). Previously dated (Steventon & Kutzbach 1988: 371).

*Comment:* a total of 193 storage pits were excavated on a ridge north of cemetery; majority are contemporary with each other.

<b>WIS-1979.</b>	<b>380 ± 70</b> $\delta^{13}C = -26.6\text{‰}$
Sample from Feature 1, S01 W97, 32cm below surface. Burial goods were found with each of three individuals recovered during limited testing.	
<b>WIS-2027.</b>	<b>420 ± 70</b> $\delta^{13}C = -26.9\text{‰}$
Sample from Feature 1, S01 W97, 70 - 80cm depth.	
<b>WIS-2028.</b>	<b>470 ± 70</b> $\delta^{13}C = -27.3\text{‰}$
Sample from Feature 1, S01 W97, 80 - 90cm depth.	
<b>WIS-2029.</b>	<b>310 ± 70</b> $\delta^{13}C = -27.0\text{‰}$
Sample from Feature 1, S01 97, 40 - 50cm depth.	
<b>WIS-2030.</b>	<b>400 ± 60</b> $\delta^{13}C = -27.0\text{‰}$
Sample from Feature 1, S01 W97, 50 - 60cm depth.	
<b>WIS-2031.</b>	<b>450 ± 50</b> $\delta^{13}C = -27.1\text{‰}$
Sample from Feature 1, S01 W97, 60 - 70cm depth.	
<b>WIS-1980.</b>	<b>500 ± 60</b> $\delta^{13}C = -25.8\text{‰}$
Sample from Feature 3, N97 W56, 90 - 100cm depth.	
<b>WIS-1981.</b>	<b>360 ± 60</b> $\delta^{13}C = -25.9\text{‰}$
Sample from Feature 7, N99 W56, 100 - 110cm depth.	
<b>WIS-2015.</b>	<b>480 ± 190</b> $\delta^{13}C = -26.5\text{‰}$
Sample from Feature 11, N64 W47, refuse pit, 20 - 70cm depth.	
<b>WIS-2016.</b>	<b>240 ± 50</b> $\delta^{13}C = -25.3\text{‰}$
Sample from Feature 1, N54 W39, 30 - 40cm depth.	



**Tremaine site (47Lc95) series**

Charcoal coll 1987-1988 from Tremaine site, LaCrosse Co (43°56'48"N, 91°15'50"W) by J A Evanson, K Kachel, D Kluth, M O'Malley, S Osborn, S Salzsieder and D Witkowski and subm by J T Penman. Ceramics recovered from features at Tremaine site are similar to Oneota wares at Ot site, above (Penman 1984).

*Comment:* Tremaine village complex covers ca 48ha and incorporates various site numbers (47Lc95, Lc149, Lc262 and Lc359). Since no European trade goods were found, complex is assumed to be prehistoric.

**WIS-2042.** **560 ± 60**

Sample from Feature 9, S31 E170, 30 - 90cm depth.  $\delta^{13}C = -27.0\text{‰}$

**WIS-2026.** **760 ± 70**

Sample from Feature 5, N12 W8, 100 - 110cm depth.  $\delta^{13}C = -22.3\text{‰}$

**WIS-2039.** **480 ± 60**

Sample from Feature 1, N12 W16, 70 - 80cm depth.  $\delta^{13}C = -27.1\text{‰}$

**WIS-2040.** **590 ± 50**

Sample from Feature 5, N12 W8, 80 - 100cm depth.  $\delta^{13}C = -26.5\text{‰}$

**WIS-2041.** **350 ± 60**

Sample from Feature 3, N18 W6, 50 - 100cm depth.  $\delta^{13}C = -26.9\text{‰}$

**WIS-2068.** **540 ± 70**

Sample from Feature 5, N12 W8, 100 - 120cm depth.  $\delta^{13}C = -26.1\text{‰}$

**WIS-2052.** **1470 ± 50**  
 $\delta^{13}C = -26.1\text{‰}$

Sample from Feature 8, N142 W50, 50 - 60cm depth. No diagnostic artifacts.

**WIS-2063.** **1630 ± 50**  
 $\delta^{13}C = -26.2\text{‰}$

Sample from Feature 8, N140 W50, 50 - 60cm depth. No diagnostic artifacts.

**Bachmann site (47Sb202) series**

Charcoal coll 1986-1987 from Bachmann site, Sheboygan Co (43°43'N, 87°48'W) by L A Rusch and S K Osborn and subm by J T Penman (Rusch & Penman 1984; Steventon & Kutzbach 1986: 1211; 1987: 402; 1988: 371).

**WIS-1982.** **250 ± 50**

Sample from Feature 33.  $\delta^{13}C = -27.7\text{‰}$

**WIS-1983.** **1100 ± 70**

Sample from Feature 73.  $\delta^{13}C = -26.2\text{‰}$

**WIS-2038. Double site (47Pi81)** **890 ± 220**

Charcoal from Double site, Pierce Co (44°39'N, 92°38'W) coll July 1984 and subm by J T Penman. Oak charcoal from Mound "A", 50-70cm depth. Site contained 35 linear and conical mounds when mapped in 1887. Previously dated (Steventon & Kutzbach 1987: 401; Penman 1984).

**Fred Edwards site (47Gt377) series**

Wood charcoal coll Aug 1987 from Fred Edwards site, Grant Co (42°43'30"N, 90°50'58"W) by F Finney and subm by J B Stoltman, Dept Anthropol, Univ Wisconsin-Madison. Samples date Middle Mississipp/Late Woodland contact in SW Wisconsin (Steventon & Kutzbach 1986: 1211; 1987: 403; 1988: 371).

**WIS-2044.** **840 ± 70**  
 $\delta^{13}C = -27.2\text{‰}$

Sample from Feature 155, a structure with a basin 30m deep containing two distinct fill episodes and five ceramic vessels.

**WIS-2061.** **840 ± 70**  
 $\delta^{13}C = -26.7\text{‰}$

Sample from Feature 148, Post 11, a palisade line located at S end of site. Twenty posts were excavated during 1987 field season.

**WIS-2062.** **1040 ± 50**  
 $\delta^{13}C = -26.5\text{‰}$

Sample from Feature 148, Post 12 (same as WIS-2061, above).

**Viola Rockshelter site (47Ve640)**

Wood charcoal coll Sept 1980 from Viola Rockshelter, Vernon Co (43°28'38"N, 90°41'15"W) and subm by J Theler, Mississippi Valley Archaeology Center, La Crosse.

**WIS-2105.** **1220 ± 70**  
 $\delta^{13}C = -26.5\text{‰}$

Sample from Feature 3, a deep pit with west half eroded down a slump bank. Ceramics exhibit Havana-ware characteristics.

**WIS-2106.** **1810 ± 80**  
 $\delta^{13}C = -26.3\text{‰}$

Sample from Test Pit F, area B, a neatly stratified burned layer containing large sherds from a single vessel that compares to Prairie ware with grit temper rather than sand temper.

**Midway Village site (47Lc19) series**

Wood charcoal coll 1984-1988 from Midway Village site, La Crosse Co (43°56'35"N,

91°16'53"W) by J Gallagher, R Boszhardt, R Rodell and A La Fond and subm by R Boszhardt, Mississippi Valley Archaeology Center, La Crosse.

**WIS-2107.** **300 ± 50**  
 $\delta^{13}C = -26.2\text{‰}$

Sample from Feature 2 (W 1/2), Zone A, containing large quantities of refuse representing last usage. Pit contained 2 Oneota vessels, 1 with bold vertical finger trails and 1 with a unique variety of Allamakee trailed of the Valley View phase.

**WIS-2108.** **650 ± 50**  
 $\delta^{13}C = -26.2\text{‰}$

Sample from Feature 89, Zones A and B, a stratified basin-shaped pit containing a large section of an Oneota vessel that compares with Brice Prairie phase type Perrot Punctated.

**WIS-2109.** **470 ± 50**  
 $\delta^{13}C = -26.1\text{‰}$

Sample from Feature 222, Level 7, underlying a layer of ash and charcoal containing an Oneota rim section of a Perrot Punctate vessel that represents a Brice Prairie phase occupation.

**WIS-2110.** **440 ± 50**  
 $\delta^{13}C = -26.9\text{‰}$

Sample from Feature 234, a large shallow basin pit containing Valley View phase Allamakee trailed ceramics.

**WIS-2111.** **610 ± 50**  
 $\delta^{13}C = -26.0\text{‰}$

Sample from Feature 276, a shallow basin pit containing a large section of an Oneota vessel with Allamakee trailed and Lake Winnebago trailed attributes.

**WIS-2112.** **570 ± 50**  
 $\delta^{13}C = -21.1\text{‰}$

Sample from Feature 2(W 1/2), Zone B, representing the lower portion of a large storage/processing pit. See WIS-2107, above.

#### **Old Spring site series (47Wn350)**

Charred wood coll July 1987 from Old Spring site, Winnebago (44°10'N, 88°52'W) and subm by D F Overstreet, Great Lakes Archaeological Research Center, Inc, Milwaukee. Samples from burned structural timbers in semi-subterranean houses and from single-episode storage/refuse pits. Occupation represents earliest well-defined Oneota complex (McKern phase) in E Wisconsin. Dates clarify relationship between Emergent Mississippian and Oneota.

**WIS-2087.** **730 ± 50**  
 $\delta^{13}C = -25.8\text{‰}$

Sample from Feature 200, storage/refuse pit.

<b>WIS-2088.</b>	<b>770 ± 50</b>
Sample from Feature 167, storage/refuse pit.	$\delta^{13}C = -26.3\text{‰}$
<b>WIS-2092.</b>	<b>730 ± 60</b>
Sample from Feature 117, storage/refuse pit.	$\delta^{13}C = -25.7\text{‰}$
<b>WIS-2093.</b>	<b>880 ± 50</b>
Sample from Feature 110, storage/refuse pit.	$\delta^{13}C = -26.4\text{‰}$
<b>WIS-2094.</b>	<b>810 ± 50</b>
Sample from Feature 158, storage/refuse pit.	$\delta^{13}C = -26.8\text{‰}$
<b>WIS-2095.</b>	<b>750 ± 50</b>
Sample from Feature 156, storage/refuse pit.	$\delta^{13}C = -25.7\text{‰}$
<b>WIS-2096.</b>	<b>700 ± 50</b>
Sample from Feature 179E, burial pit in house floor.	$\delta^{13}C = -25.7\text{‰}$

*Algeria*

<b>WIS-2067. Khanguet-el-Mouhaad site</b>	<b>7170 ± 80</b>
	$\delta^{13}C = -24.5\text{‰}$

Charcoal coll 1928 from Ain Mouhaad, Tebessa near Algerian-Tunisian border (35°39'N, 08°25'W) by P Nesbitt and DeBruge. Subm by D E Shea, Logan Mus, Beloit Coll, Wisconsin (Pond *et al* 1938; Briggs 1955; Lubell 1984).

*Comment:* sample was submitted as upper Capsian 6000-9500 BP and dated to add information on the archaeology of the Algerian Sahara.

*Pakistan***Harappa site series**

Wood charcoal coll 1987 from Harappa, Dist Sahiwal, Punjab (30°38'N, 72°52'E) by expedition from Univ California-Berkeley, directed by G F Doles. Samples subm by Asst Dir, J M Kenoyer, Univ Wisconsin-Madison.

<b>WIS-2043.</b>	<b>3770 ± 70</b>
	$\delta^{13}C = -25.5\text{‰}$
Sample from Lot 526, upper level of mature Harappan habitation on Mound AB.	
<b>WIS-2053.</b>	<b>3920 ± 210</b>
Sample from Lot 309 and 311, topmost layers of mature Harappan habitation on Mound E.	

**WIS-2074.** **3700 ± 60**  
 $\delta^{13}C = -25.9\%$

Sample from Lot 798, Feature 7b, lower layer of a hearth filled with ash and charcoal. Upper and lower layers were divided by mud plaster which was burned red and had chaff impressions.

**WIS-2075.** **3830 ± 60**

Sample from Lot 547, Feature 25, fill above Floor 25.  $\delta^{13}C = -23.0\%$

### *Portugal*

#### **Agroal site series**

Charcoal coll July 1988 from Agroal, Vila Nova de Ourém (39°40'45"N, 08°26'15"W) and subm by K T Lillios, Dept Anthropology, Yale Univ, New Haven, Connecticut. Three samples coll from levels associated with flint and quartzite cores, flakes and bladelets, and handmade ceramics.

*Comment:* believed to be contemporary with site's Bronze-Age occupation. Dates, however, which range from the 13th - 17th centuries AD are contemporary with much of excavated ceramics and coins recovered in later levels of site. Significant disturbance of site's Bronze-Age levels, perhaps due to tilling, must account for association of recent charcoal with prehistoric artifacts.

**WIS-2081.** **310 ± 50**

Sample from Pits 16-23, Level 5 (70cm depth), 147m elevation.  $\delta^{13}C = -24.8\%$

**WIS-2082.** **450 ± 50**

Sample from Pit 14, Level 3a (45cm depth), 145m elevation.  $\delta^{13}C = -25.3\%$

**WIS-2083.** **670 ± 50**  
 $\delta^{13}C = -24.8\%$

*Olea* sp and *Crataegus* sp from Pits 12 and 13, Level 3a (45cm depth), 145m elevation. Charcoal identified by L McWeeney, Yale Univ.

### GEOLOGIC SAMPLES

#### *United States*

#### *Alaska*

#### **Sitkinak Island series**

Samples coll July 1988 from Sitkinak Island (56°35'N, 154°05'W) and subm by T Byrne, Geological Science Dept, Brown Univ, Providence, Rhode Island. Dated to provide information on a recently active fault zone.

**WIS-2077.** **2060 ± 50**

Intertidal mud and surf grass (*Phyllospadix*) from uplifted marine terrace 2m above mean sea level.

**WIS-2078.** **3140 ± 60**

Intertidal mud and surf grass (*Phyllospadix*) from uplifted marine terrace 5m above mean sea level.

**Pleasant Island site series**

Cores coll Sept 1988 from small lake area in Tongass Natl Forest (58°21'N, 135°39'W) by D R Engstrom, J Almendinger and J Janssens and subm by D R Engstrom, Univ Minnesota, Minneapolis. All depths from peat surface; elevation 150m. Previously dated (Steventon & Kutzbach 1988: 375).

**WIS-2089.** **9440 ± 100**

Bryophyte peat, 195 - 200cm depth overlying contact with mineral soil. Core taken 40cm above lake level, 15m E of E drain.

**WIS-2098.** **850 ± 50**

Bryophyte peat, 83.8 - 88.8cm depth. Same core as WIS-2089, above.

**WIS-2099.** **4060 ± 70**

Bryophyte peat, 159.7 - 164.7cm depth. Same core as WIS-2089, above.

**WIS-2090.** **7680 ± 80**

Sedge peat, 245 - 250cm depth, overlying contact with mineral soil. Core taken 392cm above lake level, 35m SE of shore.

**WIS-2091.** **8300 ± 100**

Sedge peat, 345 - 350cm depth, overlying contact with mineral soil. Core taken 333cm above lake level, 40m SW of shore.

**WIS-2100.** **10,530 ± 110**

Light brown gyttja, 574 - 582cm below lake surface, water depth 3.64m.

**WIS-2080. La Perouse** **2690 ± 60**

Core coll July 1988 from a small lake between lateral moraines of Dagelet and La Perouse Glaciers, Glacier Bay Natl Park and Preserve (58°31'N, 137°18'W) by H E Wright, Jr and D R Engstrom and subm by D R Engstrom. Peat, 86 - 92cm from water/sediment interface, water depth 5.3m. Dates minimum age of lake basin and ice retreat from early Neoglacial advance.

**WIS-2101. Dagelet** **1080 ± 60**

Core coll July 1988 from a small lake at terminus of Dagelet Glacier, Glacier Bay Natl Park

and Preserve (58°31'N, 137°20'W) by H E Wright, Jr and D R Engstrom and subm by D R Engstrom. Limnic sediment, 22 - 31cm from water/sediment interface, water depth 3.8m. Dates minimum age of lake basin and ice retreat from early Neoglacial advance.

**WIS-2104. Brady****1230 ± 50**

Core coll July 1988 from a small lake at terminus of Brady Glacier, Glacier Bay Natl Park and Preserve (58°19'N, 136°41'W) by H E Wright, Jr and D R Engstrom and subm by D R Engstrom. Limnic sediment, 35 - 44cm below water/sediment interface, water depth 7.7m. Dates minimum age of lake basin and ice retreat from early Neoglacial advance.

*California***WIS-2086. Gumboot Lake****11,510 ± 110**

Core coll Sept 1988 from Gumboot Lake, Shasta Co (41°12'30"N, 122°30'30"W) and subm by M Edwards, Dept Geography, Univ Oregon, Eugene. Basal sample dates minimum age for local deglaciation in Trinity Alps.

*Connecticut***Cedar Swamp series**

Core coll May 1988 from Cedar Swamp, Pequot Indian Reservation (41°27'30"N, 71°57'30"W) and subm by R S Webb, Brown Univ. Depths in cm below surface. Previously dated (Steventon & Kutzbach 1988: 376).

**WIS-2054.****2370 ± 70**

Fine-grained peat, 33 - 39cm depth.

**WIS-2055.****3930 ± 80**

Fine-grained peat, 68 - 73cm depth.

**WIS-2056.****7580 ± 80**

Fine-grained peat, 96 - 102cm depth.

*Delaware***Longhauser Pond series**

Core, 10cm diam, coll June 1987 from Longhauser Pond, New Castle Co (39°23'05"N, 75°40'30"W) and subm by R S Webb. Sampled to provide sediment accumulation rate above and below a major stratigraphic hiatus at 70cm, first noticed in Walters Puddle series (Steventon & Kutzbach 1987: 403-404). All depths from water/sediment interface, water depth 40cm.

**WIS-2007.****3410 ± 80**

Organic silt to clay, 30 - 35.5cm depth.

**WIS-2008.** **6190 ± 90**

Organic silt; rootlets removed by sieving, 64 - 69cm depth.

**WIS-2009.** **10,820 ± 100**

Inorganic to organic poor silt, 71 - 78cm depth.

**WIS-2010.** **11,610 ± 100**

Inorganic silt, sand and clay, 86 - 92cm depth.

#### **Leipsig Salt Marsh series**

Core coll June 1987 from Leipsig Salt Marsh, Kent Co (39°14'25"N, 75°31'15"W) and subm by A J Smith, Brown Univ. Dated to provide temporal control within core.

**WIS-2013.** **2230 ± 70**

Peat with silt, 316 - 321cm depth.

**WIS-2014.** **2120 ± 70**

Organic silty mud containing plant fibers, 269 - 274cm depth.

#### **Prison Pond series**

Core coll June 1987 from Prison Pond, Walker Co (39°20'20"N, 75°36'45"W) and subm by R S Webb. Measurements from water/sediment interface, water depth 55cm.

**WIS-2022.** **2650 ± 80**

Organic silt to clay, 24 - 26.5cm depth.

**WIS-2023.** **11,760 ± 150**

Inorganic to organic-poor silts, 34 - 41cm depth.

**WIS-2024. Walters Puddle** **2370 ± 80**

Core coll June 1988 from Walters Puddle, New Castle Co (39°24'N, 75°41'30"W) and subm by R S Webb. Fine silt and clay, organic-rich sediment, 25 - 28.5cm below water/sediment interface, water depth 1m. Previously dated (Steventon & Kutzbach 1987: 403-404).

#### **St Jones River series**

Core coll June 1987 from St Jones River, Kent Co (39°08'N, 75°30'W) by J E Pizzuto and subm by E E Whallon, Univ Delaware, Newark. Measurements from surface. Site contains archaeological artifacts. Dates useful for paleoenvironmental reconstruction.

**WIS-2037.** **1890 ± 220**

Matted fiber ball, 300cm depth.



**WIS-2033.** **3460 ± 80**

Peaty mud, 330 - 334cm depth.

**WIS-2034. Duck Creek** **11,480 ± 150**

Core coll June 1987 from Duck Creek, Kent Co (39°18'30"N, 75°36'W) by J E Pizzuto and subm by E E Whallon. Peat, 200 - 203cm depth. Deepest basal marsh peat in locality. Shows initiation at transgression of brackish tidal marsh into area.

**WIS-2035. Mill Creek** **1730 ± 60**

Core coll Aug 1987 from Mill Creek, Kent Co (39°18'N, 75°34'30"W) by J E Pizzuto and subm by E E Whallon. Muddy peat from 193cm below surface. Deepest evidence for marsh environment along this tidal stream.

**WIS-2036. Leipsig River site** **8020 ± 100**

Core coll Aug 1987 from Leipsig River site, Kent Co (39°14'30"N, 75°35'W) by J E Pizzuto and subm by E E Whallon. Muddy peat, 217 - 220cm below surface. Deepest evidence for marsh deposit, may mark transgression of saline tidal waters into area.

#### **Nowakowski Pond series**

Core, 10cm diam, coll June 1987 from Nowakowski Pond, New Castle Co (39°23'9"N, 75°40'40"W) and subm by R S Webb. Sampled to provide dates above and below a stratigraphic hiatus at 60cm, first noticed in Walters Puddle (Steventon & Kutzbach 1987: 403-404). All depths from water/sediment interface, water depth 32cm.

**WIS-2011.** **6190 ± 100**

Organic silt to clay, sieved to remove rootlets, 57 - 59cm depth.

**WIS-2012.** **10,580 ± 100**

Inorganic to organic poor silt, 64 - 67cm depth.

#### *Florida*

**WIS-1984. Phosphate mine site** **> 33,000**

Highly decomposed peat from open-pit phosphate mine near Bartow, Polk Co (27°51'N, 81°50'W) coll by T Ager, USGS and subm by L Shane and H E Wright, Jr, Univ Minnesota, Minneapolis. Sample dates top of 30m peat deposit under 11m of sand.

**WIS-2057. Barchampe Lake** **7290 ± 80**

Core coll March 1986 from Barchampe Lake, Jefferson Co (30°08'N, 80°08'W) by E Grimm and W A Watts and subm by W A Watts, Trinity Coll, Dublin, Ireland. Sandy lake peat, 890 - 897cm below surface. Dated to provide information on vegetation and climate history of Florida and SE United States.

*Georgia***WIS-2058. Langdale Pond****7890 ± 80**

Core coll March 1986 from Langdale Pond, Lowndes Co, near Georgia-Florida border (30°48'36"N, 83°16'59"W) by E Grimm and W A Watts and subm by W A Watts. Humified peat, 760 - 767cm below surface. Dated to provide information on vegetation and climate history of Florida and SE United States.

*Illinois***WIS-2097. Spring Hill Bog site****9780 ± 100** $\delta^{13}C = -26.4\text{‰}$ 

Wood coll 1980 from Spring Hill Bog, Whiteside Co (41°75'N, 90°00'W) by A Swain, R Steventon, K Gajewski and M Winkler and subm by M Winkler, Univ Wisconsin-Madison. Sample dates Late Glacial/Early Holocene water-level change in Rock River drainage basin.

*Massachusetts***Herring River Marsh-Estuary series**

Cores coll Oct 1986 from Herring River Marsh, Barnstable Co (41°06'N, 70°04'W) by R A Orsen and C T Roman, Center for Coastal and Environmental Studies, Rutgers Univ, New Brunswick, New Jersey. Samples subm by M Winkler, Univ Wisconsin-Madison. Dated to determine long-term accretion rates in both salt and brackish-freshwater systems. Acid treatment only.

**WIS-1986.****1610 ± 70**

Brown silt with clay, roots and rhizomes, 236 - 240cm depth. Sample HR-1-240.

**WIS-1996.****2330 ± 240**

Gray clays with sand, roots and rhizomes, 326 - 330cm depth. Sample HR-1-330.

**WIS-1997.****Modern**

Gray clays with sand, roots and rhizomes, 29 - 33cm depth. Sample BB-2-D33.

**WIS-2017.****1290 + 190**

Gray clays with sand, silt, roots and rhizomes, 151 - 155cm depth. Sample HR-3-155.

**WIS-2025.****760 ± 190**

Brown/gray clays with silt, sand, roots and rhizomes, 68 - 72cm depth. Sample DH-1-072.

**WIS-2032.****380 ± 90**

Gray clays with silt, roots and rhizomes, 46 - 50cm depth. Sample HR-5-050.

**Nipmuck Pond series**

Core coll Sept 1984 from Nipmuck Pond, Worcester Co (41°58'71"N, 71°07'30"W) by J T Overpeck, R S Thompson, and R S Webb and subm by P Tsadekis, Brown Univ. Core is being used for Holocene pollen analysis. All depths from water/sediment interface, water depth 6.3m.

<b>WIS-1987.</b>	<b>2540 ± 70</b>
Gyttja, 39.1 - 57.1cm depth.	
<b>WIS-1988.</b>	<b>4900 ± 70</b>
Gyttja, 131 - 150cm depth.	
<b>WIS-1989.</b>	<b>8590 ± 80</b>
Gyttja, 181 - 195cm depth.	
<b>WIS-1990.</b>	<b>9390 ± 100</b>
Gyttja, 206 - 221cm depth.	
<b>WIS-1991.</b>	<b>10,200 ± 100</b>
Gyttja, 276 - 285cm depth.	
<b>WIS-1992.</b>	<b>12,750 ± 120</b>
Gyttja, 456 - 495cm depth.	

**Great Pond, Truro series**

Livingstone core coll Sept 1986 from Great Pond, Truro, Barnstable Co (41°58'26"N, 70°01'59"W) by M Winkler, R Webb, J Overpeck, J Portnoy, K Gajewski and subm by M Winkler, Univ Wisconsin-Madison. All depths from water/sediment interface, water depth 9.88m. Previously dated (Steventon & Kutzbach 1988: 376). Acid treatment only.

<b>WIS-1976.</b>	<b>13,790 ± 130</b>
Gyttja, 418 - 427cm depth.	
	$\delta^{13}C = -28.9\text{‰}$
<b>WIS-2018.</b>	<b>9950 ± 90</b>
Gyttja, 374 - 380cm depth.	
<b>WIS-2019.</b>	<b>12,520 ± 120</b>
Clayey gyttja, 413 - 423cm depth.	
<b>WIS-2071.</b>	<b>1970 ± 50</b>
Gyttja, 142 - 147cm depth.	
	$\delta^{13}C = -29.6\text{‰}$

**WIS-2072.****840 ± 50**

Gyttja, 66 - 71cm depth.

 $\delta^{13}C = -30.3\text{‰}$ **Great Pond, Wellfleet series**

Livingstone core coll Oct 1986 from Great Pond, Wellfleet, Barnstable Co (41°56'25"N, 70°00'03"W) by M Winkler, R Webb, J Overpeck, J Portnoy, K Gajewski and subm by M Winkler. All depths from water/sediment interface, water depth 16.2m. Acid treatment only.

**WIS-1977.****11,670 ± 100**

Gyttja, 690 - 711cm depth. Basal date.

**WIS-2065.****4950 ± 70**

Gyttja, 186 - 194cm depth.

 $\delta^{13}C = -28.3\text{‰}$ **WIS-2066.****9910 ± 100**

Gyttja, 441 - 449cm depth.

 $\delta^{13}C = -26.6\text{‰}$ **Dyer Pond series**

Livingstone core coll Oct 1986 from Dyer Pond, Wellfleet, Barnstable Co (41°56'19"N, 70°00'35"W) by M Winkler, R Webb, J Overpeck, J Portnoy, K Gajewski and subm by M Winkler. All depths from water/sediment interface, water depth 10.5cm. Acid treatment only.

**WIS-1978.****12,530 ± 120**

Silty gyttja, 710 - 717.5cm depth. Basal date.

 $\delta^{13}C = -26.8\text{‰}$ **WIS-2070.****2960 ± 60**

Gyttja, 450 - 457cm depth.

 $\delta^{13}C = -27.9\text{‰}$ **WIS-2103.****490 ± 110**

Gyttja, 51 - 56cm depth.

 $\delta^{13}C = -28.4\text{‰}$ **WIS-2005. Duck Pond, Provincetown****960 ± 60** $\delta^{13}C = -28.4\text{‰}$ 

Core coll Oct 1986 from Duck Pond, Barnstable Co (42°03'00"N, 70°11'30"W) and subm by M Winkler. Peaty gyttja, 103 - 103.5cm below water surface, water depth 50cm. Acid treatment only.

**WIS-2006. Bennett Pond, Provincetown****910 ± 70** $\delta^{13}C = -27.7\text{‰}$ 

Core coll Oct 1986 from Bennett Pond, Barnstable Co (42°03'30"N, 70°12'00"W) and subm by M Winkler. Gyttja from 90cm below water surface, water depth 70cm. Acid treatment only.

**McKusker's Pond series**

Livingstone core coll Aug 1985 from McKusker's Pond, Barnstable Co (941°49'23"N, 69°58'03"W) by R S Webb, E A Scharf, J Karb and S Clemens and subm by P Newby, Brown Univ. Measurements from water/sediment interface, water depth 48cm. Acid treatment only.

**WIS-2020.** **8500 ± 90**

Organic lake sediment, 248 - 253cm depth.

**WIS-2021.** **8330 ± 80**

Organic lake sediment, 263 - 267cm depth.

**High Head Dune Bog series**

Samples coll Nov 1987 from High Head area, Cape Cod Natl Seashore, Barnstable Co (42°03'30"N, 70°07'30"W) and subm by M Winkler. Acid treatment only.

**WIS-2084.** **Modern**

Sandy peat from Dune Bog #4, 7.5 - 8.5cm below surface.

**WIS-2102.** **Modern**

Organic sand from Dune Bog #5, 5 - 6cm below surface.

*Michigan***Lake Sixteen series**

Core coll Feb 1987 from Lake Sixteen, Cheboygan Co (45°35'N, 84°20'W) and subm by R P Futyma, New York State Museum, Albany. For previous dates from site, see Futyma and Miller (1986). Depth in cm from water/sediment interface, water depth 105cm. Acid treatment only.

**WIS-1999.** **7630 ± 100**

Gyttja, 192 - 196cm depth.

**WIS-2000.** **10,690 ± 100**

Silt mixed with organic lake sediment, 225 - 231cm depth.

*Ohio***East Twin Lake site series**

Core from East Twin Lake, Portage Co (41°11'50"N, 81°20'W) coll April 1988 by L C K Shane and H E Wright, Jr and subm by L C K Shane, Univ Minnesota, Minneapolis. Dated to provide vegetation/climate history of NE Ohio. Depths from water surface, water depth 11m.

**WIS-2045.** **990 ± 50**

Gyttja, 1170 - 1179cm depth.

**WIS-2046.** **2980 ± 60**

Gyttja, 1344 - 1352cm depth.

**WIS-2047.** **9290 ± 90**

Gyttja, 1802 - 1810cm depth.

**WIS-2048.** **13,660 ± 140**

Clay/silt limnic sediment, 2046 - 2058cm depth.

**WIS-2064. Andreas site** **4500 ± 70**  
 $\delta^{13}C = -26.4\text{‰}$

Core coll April 1988 from Andreas site, Portage Co (41°12'50"N, 81°21'53") by L C K Shane and H E Wright, Jr and subm by L C K Shane. Wood, 174 - 177cm below hummock surface. Dated to provide vegetation/climate history of NE Ohio.

### *Oregon*

#### **Bolan Lake series**

Core coll Sept 1988 from Bolan Lake, Josephine Co (42°01'30"N, 123°27'30"W) and subm by M Edwards, Dept Geography, Univ Oregon, Eugene. Dated to determine sedimentation rate. Depths in cm from water surface, water depth 10.9m.

**WIS-2079.** **9600 ± 100**  
 $\delta^{13}C = -26.5\text{‰}$

Wood, fir (*Abies*) identified by D Christensen, US Forest Products Lab, Madison, Wisconsin; 1841 - 1846cm depth.

**WIS-2085.** **12,360 ± 120**

Gyttja, 1967 - 1972cm depth.

### *Rhode Island*

#### **Fresh Pond series**

Core coll Jan 1988 from Fresh Pond, Block Island (41°09'30"N, 71°34'30"W) by P W Dunwiddie and R S Webb and subm by P W Dunwiddie, Massachusetts Audubon Society. All measurements from water/sediment interface, water depth 6.7m.

**WIS-2059.** **6720 ± 80**

Silty organic gyttja, 264 - 272cm depth.

**WIS-2060.** **9570 ± 100**

Silty organic gyttja, 362 - 372cm depth.

*Wisconsin***Devil's Island Bog series**

Core coll from Devil's Island, Apostle Islands, Ashland Co (47°04'N, 90°43'W) and subm by A M Swain, Univ Wisconsin-Madison.

**WIS-2002.** **5010 ± 80**

Peat and peaty clay, 95 - 105cm depth. Dates initiation of peat growth in bog.

**WIS-2073.** **1990 ± 50**

Peat, 65 - 70cm depth. Dates beginning of increase in spruce and alder pollen and decrease in birch pollen.

*Wyoming*

**WIS-2001. Soda Lake** **9750 ± 90**

Two adjacent cores coll Aug 1987 from Soda Lake, Teton Natl Forest (43°31'15"N, 110°15'W) and subm by C Barnosky, Carnegie Museum, Pittsburgh, Pennsylvania. Organic silt with shell, 1787 - 1802cm below water surface, water depth 10.65m, alt 2384m. Acid treatment only.

*Peru***Tunsho site**

Sample coll Sept 1986 from Tunsho site, Junin Prov (11°50'S, 75°06'W) and subm by H E Wright, Jr. Peat growth at this site started as soon as glacier retreated from terminal moraine.

**WIS-1969.** **250 ± 60**

Peat, 139 - 144cm depth.

**WIS-1998.** **920 ± 200**

Organic detritus from base of gravels deposited by glacial outwash from terminal moraine.

**WIS-1970. Huaytapallana Stream cut** **650 ± 60**

Sample coll Sept 1986 from stream in Nevada Huaytapallana, Junin Prov (11°50'S, 75°06'W) and subm by H E Wright, Jr. Organic detritus in silts related to retreat of Late Pleistocene glacier overlain by Late Holocene moraine.

**WIS-1971. Verdecocha B** **610 ± 70**

Basal peat coll Sept 1986 from Verdecocha, 45km S W of LaOroya, Junin Prov (11°55'S, 76°03'W) and subm by H E Wright, Jr. Peat, at 92 - 97cm depth, dates recession of Late Holocene ice from terminal moraine.

**WIS-1972. Pucuta B****420 ± 60**

Basal peat coll Sept 1986 from Pucuta, 45km SW of LaOroya, Junin Prov (11°54'S, 76°01'W) and subm by H E Wright, Jr. Peat, at 269 - 274cm depth, was formed as Late Holocene glacier retreated from terminal moraine.

**WIS-1973. Laguna Tranca Grande****11,830 ± 110**

Basal lake sediment coll Sept 1986 from Laguna Tranca Grande, Junin Prov (11°45'S, 75°45'W) and subm by H E Wright, Jr. Dates time of glacial recession from terminal moraine.

**WIS-1985. Laguna Tipicocha****7320 ± 80**

Basal lake sediment coll Sept 1987 from Laguna Tipicocha, Junin Prov (11°45'S, 75°13'W) and subm by H E Wright, Jr. Sample, at 1059 - 1067cm depth, dates time of glacial recessional lake formation.

**Lake Tuctua series**

Core coll Sept 1986 from Laguna Tuctua, Junin Prov (11°43'S, 74°57'W) and subm by H E Wright, Jr. Samples provide sediment accumulation rate and pollen influx. Previous date, WIS-1940 (Stevenson & Kutzbach 1988: 382). Depth measurements from water surface, water depth 8.7m

**WIS-2003.****3880 ± 80**

Organic lake sediment, 1000 - 1005cm depth.

**WIS-2004.****6060 ± 80**

Organic lake sediment, 1145 - 1155cm depth.

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## NOTES AND COMMENTS

### CALIBRATING NEW ZEALAND RADIOCARBON DATES OF MARINE SHELLS

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**ABSTRACT.** Radiocarbon activity of 11 modern marine shell samples from the New Zealand region is enhanced compared with the surface layers of the average world ocean. The measured enhancement,  $\Delta R$ , is equivalent to  $-31 \pm 13$  years. On this basis, the Institute of Nuclear Sciences will now use a value of  $-30$  years in reporting calibrated ages for marine shell samples.

#### INTRODUCTION

Stuiver, Pearson and Braziunas (1986) modeled the history of radiocarbon variations in the surface ocean layers using measured atmospheric changes and knowledge of gas exchange rates between the atmosphere and the oceans. The resulting calibration curve for the average world ocean has a long-term trend which parallels that of the atmosphere, with much smoother short-term variations.

To use the curve for a particular region, we calculate a factor,  $\Delta R$ , which is a measure of the regional enhancement or depletion of radiocarbon due, for example, to local anomalies such as upwelling of old sea water.  $\Delta R$  is the difference between the radiocarbon activity of the regional ocean and the surface layers of the average world ocean in AD 1950. Calculation of  $\Delta R$  is based on the conventional radiocarbon age of samples of known calendar age collected from the area. Stuiver, Pearson and Braziunas (1986) give values for many parts of the world including New Zealand. The value given for New Zealand ( $-65 \pm 25$  yr) was calculated from the results of five samples, four of which were unreferenced (Stuiver, Pearson & Braziunas 1986, Table 1). We present here a new estimate of  $\Delta R$  for the New Zealand region, which is based on 11 marine shell samples dated by the Institute of Nuclear Sciences, for which we are confident of the actual age and provenience.

#### CALCULATION OF $\Delta R$

Table 1 lists the 11 shell samples. Some of these results include early measurements in which samples were compared to a *Pinus radiata* standard. These were modified slightly from previously published values following a re-evaluation of this older standard relative to the conventional NBS oxalic acid standard (Melhuish, pers commun, 1989). McFadgen (1978) previously published Samples 1-7. Samples 8-11 were not published; Table 2 lists sample details. We calculated conventional ages with respect to the 0.95 oxalic acid standard and included isotopic fractionation corrections as defined by Stuiver and Polach (1977). We determined model age from Stuiver, Pearson and Braziunas (1986, Fig 10A). The difference between conventional age and model age for each sample is an estimate of  $\Delta R$ . The estimates range between  $-100$  and  $+40$  years. The range is not significant (T' test, Ward & Wilson 1978, Chi-squared = 9.07, df = 10, P = 0.525);

TABLE 1  
Calculation of  $\Delta R$

Sample	Date coll	Date run	NZ no.	R no.	PR no.	$\delta^{13}\text{C}$	$\Delta^{14}\text{C}$	Conv age (P)	Model age (Q)	$\Delta R$ (P-Q)
1	1955	1956	2439	42/2	A0854	+1.2	-52 $\pm$ 5	427 $\pm$ 39	490	-63 $\pm$ 39
2	1953	1957	114	151/1	A0886	-1.3	-62 $\pm$ 5	506 $\pm$ 39	490	+16 $\pm$ 39
3	1957	1958	3203	333/1B	A1193	+0.4	-60 $\pm$ 5	489 $\pm$ 40	490	-1 $\pm$ 40
4	1954	1972	1481	4292/1	A6284	+2.7	-62 $\pm$ 4	494 $\pm$ 35	490	+4 $\pm$ 35
5	1949	1973	1813	4349	C0221	-0.2	-55 $\pm$ 6	432 $\pm$ 46	490	-58 $\pm$ 46
6	1925	1973	1814	4350	C0218	+1.1	-65 $\pm$ 7	515 $\pm$ 56	475	+40 $\pm$ 56
7	1923	1973	1799	4519/1	C0340	+0.2	-52 $\pm$ 6	410 $\pm$ 46	475	-65 $\pm$ 46
8	1954	1979	4698	5823/1	A7733	+0.8	-58 $\pm$ 4	451 $\pm$ 32	490	-39 $\pm$ 32
9	1954	1955	2421	AB1192/7	A0322	-0.6	-52 $\pm$ 8	422 $\pm$ 62	490	-68 $\pm$ 62
10	1954	1955	2433	AB1519/1	A0335	+3.2	-57 $\pm$ 8	464 $\pm$ 62	490	-26 $\pm$ 62
11	1954	1955	2431	AB1402/1A	A0343	-0.9	-48 $\pm$ 6	390 $\pm$ 44	490	-100 $\pm$ 44

Weighted mean of  $\Delta R$  = -31  $\pm$  13 years  
Scatter in unweighted mean = 41 years

Range of  $\Delta R$  is not significant  
(Chi-squared = 9.07 df = 10, P = 0.525)

we can infer no significant variation in the radiocarbon activity of surface sea water around New Zealand from these data. The weighted mean of  $\Delta R$  has a value of -31  $\pm$  13 years.

Early measurements of dissolved inorganic carbon in surface sea waters in the New Zealand region give closely comparable  $\Delta^{14}\text{C}$  values to those shown in Table 1. For example, NZ2419, collected December 1954, gave  $\Delta^{14}\text{C}$  = -53  $\pm$  8‰ and NZ2751, collected September 1956, gave  $\Delta^{14}\text{C}$  = -58  $\pm$  5‰.

TABLE 2  
Details of Samples 8-11 (unpub). All 4 samples are from the west Wellington coast on the southwest corner of the North Island

Sample	Shell species	Provenience
8	<i>Alcithoe arabica</i>	Pauatahanui Inlet
9	<i>Haliotis</i> sp	Makara Beach
10	<i>Cellana</i> sp	Makara Beach
11	<i>Chione stutchburyi</i>	Makara Beach

#### CALIBRATION OF NEW ZEALAND MARINE SHELL DATES

New Zealand marine shell dates have usually been reported by the Institute of Nuclear Sciences with respect to a New Zealand Marine Shell Standard. The standard was intended to take into account radiocarbon depletion of the marine environment by making a constant offset to the conventional radiocarbon age.

Rafter *et al* (1972) estimated the depletion from one shellfish collected live from Pounawea in 1955, which gave a  $\Delta^{14}\text{C}$  of -54‰ for the marine environment in 1950. In order to compensate for depletion of  $^{14}\text{C}$  in the surface oceans due to burning of fossil fuels, a further correction of +13‰ is applied to samples from the pre-industrial marine environment, based on a simple 3-box carbon cycle model developed by O'Brien (Rafter 1968). The net estimated depletion of -41‰ gave an offset of 336 years (Jansen 1984).

More recent ocean carbon models (eg, Maier-Raimer & Hasselmann 1987; Toggweiler, Dixon & Bryan 1989) suggest that the surface of the western Pacific Ocean would have been rather more depleted in <sup>14</sup>C in pre-industrial times and, hence, a larger correction should be used. We consider that such models are not yet robust enough to be used to calibrate radiocarbon dates.

A serious defect in using a constant correction for marine shells is that it does not allow for secular variations in atmospheric and oceanic <sup>14</sup>C. The effect of secular changes in the world average surface ocean value for <sup>14</sup>C over the last 2000 years has been at least as large as the industrial effect, and in the opposite direction (Stuiver, Pearson & Braziunas 1986, Fig 3). Stuiver, Pearson and Braziunas' calibration procedure, which we prefer, allows for simultaneous consideration of both secular and regional variation of <sup>14</sup>C in the marine environment.

Until such time as a better calibration procedure is determined, the Institute will report calibrated ages for marine shells from the New Zealand region using the marine calibration curve of Stuiver, Pearson and Braziunas (1986), and  $\Delta R = -30$  years. Note that we implicitly assume that  $\Delta R$  itself has not changed with time (eg, that there has been no change in ocean circulation patterns affecting the New Zealand region) because we have no historical marine samples of known age with which to determine such a change.

Previously reported shell dates may be converted to calibrated dates under the new procedure using Stuiver, Pearson and Braziunas' (1986) calibration curve, either in graphic form or in the computer program (Stuiver and Reimer 1986). The old marine shell dates are first converted to conventional dates by adding 336 years to the dates reported in terms of the 5568-yr half-life. If dates are to be converted graphically, then Stuiver, Pearson and Braziunas' curve (1986, Figs 11A-S) should be used with  $\Delta R = -30$  years. If the computer program is used, then  $\Delta R$  (-30 years), and the standard error of  $\Delta R$  ( $\pm 13$  years), should be entered at the appropriate prompts.

If the above procedure is used to correct previously reported dates to calibrated dates using Method A of Stuiver and Reimer (1986), the magnitude of the correction can be summarized as follows in Table 3:

TABLE 3  
Difference between previously reported ages and ages calibrated using  $\Delta R = -30$  years

Previously reported age (yr BP)	Approximate change in years (new calibrated age - previously reported age)
250 - 500	between +20 and -30, variable
500 - 750	between -10 and -90, decreasing with age
750 - 1650	between -70 and -120, variable
1650 - 2100	between -100 and 0, increasing with age

#### ACKNOWLEDGMENT

Shell Sample 8 was kindly provided by the National Museum of New Zealand.

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**APPLICABILITY OF 'NEW TECHNOLOGY' SCINTILLATION COUNTERS  
(PACKARD 2000 CA/LL AND 2260 XL) for  $^{14}\text{C}$  DATING**

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**ABSTRACT.** The results of this study indicate that scintillation counters employing burst-counting circuitry are capable of producing accurate age measurements. Replicate analyses confirm the validity of the minimum error of 50-60 years quoted on routine age measurements carried out at this laboratory.

**INTRODUCTION**

We have conducted in this laboratory during the past two years a great deal of research into the use of the Packard range of counters employing burst-counting circuitry, with particular emphasis on their applicability to  $^{14}\text{C}$  dating (Cook, Harkness & Anderson 1989; Cook *et al* 1989, 1990). The results of these studies have demonstrated how it is possible to maximize efficiency and stability of counting conditions by careful optimization of the scintillation cocktail. Nevertheless, the ultimate criterion for assessing the counters' applicability for  $^{14}\text{C}$  dating must be the production of accurate and precise age measurements. To formally assess this, we undertook a number of replicate analyses on a large sample of oak known to have an age in excess of 5000 BP. This allowed us to assess the precision on replicate analyses and relate this to the quoted minimum error on routine measurements. We synthesized sufficient benzene to measure 4.5g in an 'old technology' counter (Packard 4530) and 2g in the Packard 2000 CA/LL and 2260 XL (new technology). Results of the recently completed International Collaborative Study (Scott *et al* 1990) demonstrated no systematic laboratory bias from measurements made on the Packard 4530. Thus, we could compare with a system of proven accuracy.

**EXPERIMENTAL**

A large section of oak constituting ca 100 years' growth was finely chopped and subjected to alternate acid and alkali extractions followed by bleaching with hypochlorite solution to produce cellulose. The cellulose was then further ground, thoroughly mixed and split into several sub-samples of sufficient size to synthesize ca 7g of benzene. We vialled 4.5g of the benzene into 20ml glass-sealable low-potassium borosilicate ampules, using butyl-PBD bis-MSB in toluene as the scintillation cocktail (Stenhouse & Baxter 1983). This technique is not used in either the 2000 CA/LL or 2260 XL. Instead, a cocktail consisting of butyl-PBD/bis-MSB dissolved in benzene is weighed into standard 7ml low-potassium screw-cap vials. The benzene is then removed by freeze drying. Sufficient cocktail is added to make the ultimate ratio of fluors/sample benzene 2.8mg butyl-PBD and 3.0mg bis-MSB/g of benzene. We made this modification to eliminate possible variations in dissolved oxygen in the samples from the sealing process on 7ml ampules, which could influence the pulse-shape analysis and lead to variations in counting efficiency (Cook *et al* 1989).

We synthesized seven replicate samples of the cellulose to benzene. We then counted the 4.5g samples solely in the Packard 4530 (2400 min) while the 2g samples were counted first in the Packard 2260 XL (2500 min) and then in the Packard 2000 CA/LL (2500 min).

## RESULTS

The results in Table 1 indicate no significant differences between the weighted means of the seven age measurements  $\pm 1$  standard deviation ( $\sigma$ ). Indeed, those of the Packard 2000CA/LL and 2260 XL are identical ( $5519 \pm 23$  BP) whereas that of the Packard 4530 is highly comparable ( $5507 \pm 20$  BP). Similarly, when one estimates a simple mean on the 7 measurements for each counter, only 6 years separate the 3 counters under study. Further, the standard deviations are quite consistent with the error on an individual measurement. For the Packard 4530, the standard deviation is slightly higher (56 years, *cf ca* 46); for the 2000 CA/LL, it is somewhat lower (37 *cf ca* 60) and for the 2260 XL, they are virtually identical (57 *cf ca* 60).

TABLE 1  
Estimation of replicate error and intercomparison of old technology (Packard 4530)  
and new technology (Packard 2000 CA/LL and 2260 XL) scintillation counters

Replicate no.	Conventional ages BP		
	Packard 4530	Packard 2000 CA/LL	Packard 2260 XL
1	5489 $\pm$ 48	5469 $\pm$ 67	5469 $\pm$ 67
2	5500 $\pm$ 49	5525 $\pm$ 62	5581 $\pm$ 59
3	5630 $\pm$ 52	5562 $\pm$ 58	5495 $\pm$ 59
4	5486 $\pm$ 47	5531 $\pm$ 52	5521 $\pm$ 61
5	5477 $\pm$ 46	5463 $\pm$ 60	5586 $\pm$ 62
6	5468 $\pm$ 39	5525 $\pm$ 60	5430 $\pm$ 60
7	5536 $\pm$ 43	5543 $\pm$ 64	5541 $\pm$ 55
Mean $\pm 1\sigma$	5512 $\pm$ 56	5517 $\pm$ 37	5518 $\pm$ 57
Weighted mean $\pm 1\sigma$	5507 $\pm$ 20	5519 $\pm$ 23	5519 $\pm$ 23

## CONCLUSIONS

We conclude from the results presented here that the new Packard scintillation counters employing burst-counting circuitry are capable of producing accurate age measurements. The results were entirely consistent with those from a Packard 4530, which was successfully used in the recent International Collaborative Study (Scott *et al* 1990). Further, the results are consistent with a minimum error of 50-60 years generally quoted on routine age measurements.

We stress, however, that the performance of this type of new technology scintillation counter can vary according to the scintillation cocktail employed. The one used in this study was selected only after exhaustive research.

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## RADIOCARBON UPDATES

The editors are instituting this new section to report news and events that we think will be of interest to our readers. Please let us know if you have newsworthy items to include here by contacting Renee Kra, Managing Editor.

### *New Organization*

The Association of Carbon-14 Laboratories (ACL) has been established. WG Mook of the Isotope Physics Laboratory, Groningen, is Coordinator. *RADIOCARBON* is the communication medium among laboratories. Address news items to Austin Long, Editor. All other correspondence should be sent to Prof Mook. One of the functions of ACL is to provide assistance to radiocarbon laboratories in countries that do not have access to hard currency. To date, *RADIOCARBON* has sent current subscriptions to five laboratories at a reduced rate paid for by ACL. Annual membership fees will be set at the price of dating one sample. Please wait for a forthcoming letter from WG Mook with more details.

### *Publications*

The editors of *RADIOCARBON* regret to announce that the publication of the Proceedings of the 13th International Radiocarbon Conference, Dubrovnik, Yugoslavia - Volume 31, No. 3, 1989 - has been delayed. We are making every effort to speed up the printing process, and hopefully, the Proceedings will appear this summer. In the meantime, our regular publication schedule continues.

The Proceedings of the International Workshop on Intercomparison of Radiocarbon Laboratories, Glasgow, September 12-15 1989 will appear in our next issue, Volume 32, No. 3, 1990. Subscribers will automatically receive this issue, which also may be purchased separately for \$40.00.

"Radiocarbon After Four Decades" will be a co-publication between *RADIOCARBON* and the University of Arizona Press. This will be the symposium volume for the commemorative meeting in Lake Arrowhead, California, June 4-8, 1990. The publication will be a hardcover volume, edited by RE Taylor, Austin Long and Renee Kra. It will be offered at a discount to subscribers; it will not be part of the regular *RADIOCARBON* series.

### *Moves*

Prof WG Mook is the new director of The Netherlands Institute for Sea Research (NIOZ) in Texel. He will still keep 20% of his position at the Isotope Physics Laboratory in Groningen. At present, Dr Hans van der Plicht is acting director of the lab.

Archie Kaufman of the Weizmann Institute has left the field of radiocarbon dating for his first love, the U series. He is presently on sabbatical at the University of Quebec.

Stephen W Robinson has left the USGS, Menlo Park. The last we heard, he was meeting-hopping in Europe.



Charles S Tucek of Radiocarbon Ltd of Lampasas, Texas, has driven his equipment-laden vehicle to Tucson, where he has joined the staff of the Environmental Radioisotope Center at The University of Arizona.

Bob Otlet and Jill Walker have left the Isotope Measurements Laboratory to set up a new, private carbon-14 measurement laboratory, called, at present, Radiocarbon Dating. They can be contacted at Downs Croft, The Holloway, Harwell, Oxon (Tel 235 835386) and would welcome calls from old friends and colleagues.

The Harwell Isotope Measurements Laboratory has been amalgamated with the Uranium Series Disequilibrium section at Harwell under Dr Miro Ivanovich and will continue to function with Dr Jeremy Dearlove as the Laboratory Manager, no longer carrying out archaeological dating but concentrating on industrial applications. Any correspondence pertaining to radiocarbon measurements should be directed to Dr Dearlove.

#### *Retirements*

Gordon Pearson of the Queen's University of Belfast has retired. Gerry McCormac is his successor.

Prof Dr HW Scharpenseel of the University of Hamburg has retired.

Raymond L Steventon of the University of Wisconsin-Madison has retired. Dr Christine Prior is the new director of this lab.

#### *Honors*

We extend congratulations to friends and associates who were recently elected to the National Academy of Sciences:

C Vance Haynes, Jr - The University of Arizona

Patrick V Kirch - University of California, Berkeley

Hans Oeschger - Physics Institute, University of Bern, Switzerland

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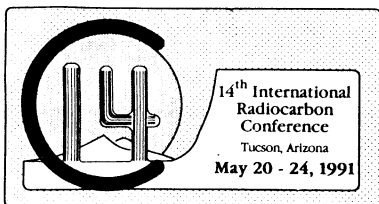
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### CALL FOR ABSTRACTS

The date of the 14th International Radiocarbon Conference, May 20-24, 1991, is fast approaching. Participants who wish to present a paper(s) should submit an abstract(s) before September 15, 1990. The abstract(s) should be double spaced and should not exceed 200 words. Margins should measure 1.5in or 3.5cm on all four sides. Please include the title, author(s) and full address(es) at the top and provide telephone, telex, fax numbers and e-mail address in the cover letter. Send your abstract(s) to Dr. Austin Long at the above address.

Abstracts will be considered for inclusion in one of the prescribed sessions. Please indicate the session most suitable for each submitted abstract. Also indicate if you prefer to present your paper(s) in poster form:

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Specialized pre-conference workshops or short courses may include:

- Liquid scintillation counting
- Prospects for Temporal Extension of Radiocarbon Calibration
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Please note our slightly revised timetable. The second circular will be sent in October, 1990 instead of May 1, 1990 and revised abstracts and registration will be due December 15, 1990. The second circular will contain full instructions for registration and hotel reservations.

The registration fee will be \$175 before December 15, 1990 and \$200 afterwards. The banquet will cost an additional \$30 (credit cards accepted).

The conference will be at the Westward Look Resort, 245 East Ina Road, Tucson, AZ 85704. Tel: (602)297-1151; Telex: 165518; Fax: (602)297-9023; Toll-free numbers: Out-of-State (800)722-2500, In-State (800)624-5317.

The rate will be \$60/room - single or double - plus tax (credit cards accepted). The same rate will apply 4 days before and after the conference. Every room has a refrigerator and wet bar. Full information and reservation packets will accompany our second circular.

Evening and social activities will include a conference reception and banquet, a trip to the Arizona Sonora Desert Museum and Old Tucson, laboratory tours, an optional trip to Kitt Peak National Observatory, companion tours and post-conference tours to the Grand Canyon and the Murray Springs Clovis site. Alternative tours are being planned.

Please note that air fares into Phoenix are generally lower than into Tucson. We are arranging a direct shuttle from both Phoenix and Tucson airports to the hotel.

**Remember - Abstracts are due September 15, 1990**

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Since its inception, the basic purpose of *RADIOCARBON* has been the publication of compilations of  $^{13}\text{C}$  dates produced by various laboratories. These lists are extremely useful for the dissemination of basic  $^{14}\text{C}$  information.

In recent years, *RADIOCARBON* has also been publishing technical and interpretative articles on all aspects of  $^{14}\text{C}$ . We would like to encourage this type of publication on a regular basis. In addition, we will be publishing compilations of published and unpublished dates along with interpretative text for these dates on a regional basis. Authors who would like to compose such an article for his/her area of interest should contact the Managing Editor for information.

Other sections recently added to our regular issues include NOTES AND COMMENTS, LETTERS TO THE EDITOR and ANNOUNCEMENTS. Authors are invited to extend discussions or raise pertinent questions to the results of scientific investigations that have appeared on our pages. These sections include short, technical notes to relay information concerning innovative sample preparation procedures. Laboratories may also seek assistance in technical aspects of radiocarbon dating. Book reviews are also encouraged as are advertisements.

*Manuscripts.* Papers may now be submitted on both floppy diskettes and hard copy. When submitting a manuscript on a diskette, always include two hard copies, double-spaced, or wait until the final copy is prepared, after review, before sending the edited diskette. We will accept, in order of preference, WordPerfect, 5.1 or 5.0, Microsoft Word, WordStar or any major Macintosh or IBM word-processing software program. ASCII files, MS DOS and CPM formatted diskettes are also acceptable. The diskettes should be either 3½" (720K or 1.44 megabytes) or 5¼" (360K or 1.2 megabytes). Radiocarbon papers should follow the recommendations in *RADIOCARBON Style Guide* (R, 1984, v 26, no. 1, p 152-158). Our deadline schedule for submitting manuscripts is:

<i>For</i>	<i>Date</i>
Vol 33, No. 1, 1991	Sept 1, 1990
Vol 33, No. 2, 1991	Jan 1, 1991
Vol 33, No. 3, 1991	May 1, 1991

*Half life of  $^{14}\text{C}$ .* In accordance with the decision of the Fifth Radiocarbon Dating Conference, Cambridge, 1962, all dates published in this volume (as in previous volumes) are based on the Libby value, 5568 yr, for the half-life. This decision was reaffirmed at the 11th International Radiocarbon Conference in Seattle, Washington, 1982. Because of various uncertainties, when  $^{14}\text{C}$  measurements are expressed as dates in years BP the accuracy of the dates is limited, and refinements that take some but not all uncertainties into account may be misleading. The mean of three recent determinations of the half life,  $5730 \pm 40$  yr, (Nature, 1962, v 195, no. 4845, p 984), is regarded as the best value presently available. Published dates in years BP can be converted to this basis by multiplying them by 1.03.

*AD/BC Dates.* In accordance with the decision of the Ninth International Radiocarbon Conference, Los Angeles and San Diego, 1976, the designation of AD/BC, obtained by subtracting AD 1950 from conventional BP determinations is discontinued in Radiocarbon. Authors or submitters may include calendar estimates as a comment, and report these estimates as cal AD/BC, citing the specific calibration curve used to obtain the estimate. Calibrated dates will now be reported as "cal BP" or "cal AD/BC" according to the consensus of the Twelfth International Radiocarbon Conference, Trondheim, Norway, 1985.

*Meaning of  $\delta^{14}\text{C}$ .* In Volume 3, 1961, we endorsed the notation  $\Delta$  (Lamont VIII, 1961) for geochemical measurements of  $^{14}\text{C}$  activity, corrected for isotopic fractionation in samples and in the NBS oxalic acid standard. The value of  $\delta^{14}\text{C}$  that entered the calculation of  $\Delta$  was defined by reference to Lamont VI, 1959, and was corrected for age. This fact has been lost sight of, by editors as well as by authors, and recent papers have used  $\delta^{14}\text{C}$  as the observed deviation from the standard. At the New Zealand Radiocarbon Dating Conference it was recommended to use  $\delta^{14}\text{C}$  only for age-corrected samples. Without an age correction, the value should then be reported as percent of modern relative to 0.95 NBS oxalic acid (Proceedings 8th Conference on Radiocarbon Dating, Wellington, New Zealand, 1972). The Ninth International Radiocarbon Conference, Los Angeles and San Diego, 1976, recommended that the reference standard, 0.95 times NBS oxalic acid activity, be normalized to  $\delta^{13}\text{C} = -19\text{‰}$ .

In several fields, however, age corrections are not possible.  $\delta^{14}\text{C}$  and  $\Delta$ , uncorrected for age, have been used extensively in oceanography, and are an integral part of models and theories. For the present, therefore, we continue the editorial policy of using  $\Delta$  notations for samples not corrected for age.

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