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*List of laboratories.* Our comprehensive list of laboratories appears annually. We are expanding the list to include additional laboratories and scientific agencies with whom we have established contacts. The editors welcome more information on these or other scientific organizations. 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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## FROM THE EDITOR

## A RETROSPECTIVE ON THE 14TH INTERNATIONAL $^{14}$C CONFERENCE

This is a public "Thank You!" from all of us in Tucson who were associated with the 14th International Radiocarbon Conference. Without your attendance and participation, our planning and efforts would have been in vain. Many of us worked long and hard, and we appreciate your compliments during and after the convention. We also received some constructive comments that will be considered at the next radiocarbon conference. Shortly after a radiocarbon conference is a good time to open a public forum on several aspects of the ways we communicate among ourselves about our research related to cosmogenic isotope research. [See *Letters to the Editor* section, this issue.]

I would like to open a discussion in the form of letters to the editor. Topics of discussion could relate to any aspect of cosmogenic isotopic research, but certain items arose at the Tucson conference that might benefit from more measured discourse. Examples include the structure of $^{14}$C conferences, selection of abstracts, agenda (or process for setting agenda) of the conference business meeting, and workable solutions to the problem of retrieval of the body of $^{14}$C dates now emerging globally at the annual rate of 12,000–15,000.

Let me start the discussion by outlining the assumptions the Tucson Conference Organizing Committee made about the preferences of the radiocarbon community and the guidelines we followed as we planned the Tucson conference. The International Radiocarbon Conference is the *only* forum where all investigators in the field of radiocarbon can get together. It is the only meeting where β-counting and AMS people overlap. As such, it has and it will continue to have a strong emphasis on techniques and methods, as well as applications. The Radiocarbon conference has been a tradition for nearly 40 years. Traditions should be tampered with cautiously. Representatives of most radiocarbon labs expect a chance to present one talk, and we accommodated that expectation.

Although the primary reason for the conference is scientific, it is also to provide a forum for radiocarbon scientists to get together. For scientists in many countries, attendance at such a meeting enhances funding possibilities. Further, participants' abstracts accepted at a Radiocarbon Conference is the key allowing their organizations or governments to pay their way, on a three-year recurrence interval, to a nice place where they can meet old friends and catch up on the latest developments. In our preliminary meetings, the planning committee for the Tucson conference discussed how selective we should be. We were aware that the caliber of presentations would vary, but we were also aware how difficult it would be to predict quality simply from the abstracts. Some top-notch scientists submit two-line abstracts. We adopted the stance that representatives of all laboratories should at least be given a chance to present a paper on their research. Not everyone is in the front line of research in a currently fashionable field, but that does not mean that his/her work is unimportant. How else can a small $^{14}$C group with limited equipment learn about new techniques than by interacting with colleagues at a radiocarbon conference? Consequently, we concluded that we would let the attendees decide which papers to hear, rather than making that decision for them. At most times during the conference, conferees had the choice of two oral presentations, posters, or patio conversations.

To many, the poster sessions tend to be unsatisfactory. To others, they are better than oral sessions. Poster sessions are ideal for papers with detailed maps or with much specialized information. In our case, we also assigned late papers to poster sessions. One thing we learned is that we can expect never to please everyone.

Regarding theme sessions: The Paleoastrophysics Workshop had special funding to bring in some invitees. It was well-received, but it is a highly specialized segment of the radiocarbon community. We had special sessions on "Calibration and Comparisons among Dating Techniques" and "Isotopic Indicators of Global Change". We also had a well-attended workshop on calibration which brought together different fields. The response to the latter was diluted by the fact that some "global change" experts were not interested in a meeting concentrating on radiocarbon. The workshop on liquid scintillation counting attracted a large number of active participants and observers, and the workshop on paleoenvironments of the southeast Mediterranean introduced several newcomers to the radiocarbon community.

Regarding encouraging presentations on AMS and non-$^{14}$C cosmogenic isotopes: We had mixed experiences with asking AMS people to attend. Some non-$^{14}$C AMS people are not interested in attending a Radiocarbon Conference. It seems that "AMS People" are clearly a distinct and diverse group and discuss things that are of interest only to that group, such as technical details of accelerators. The proposal to combine AMS and Radiocarbon Conferences was soundly defeated at the Business Meeting. It was also defeated at the last AMS meeting in Paris in 1990 by the AMS community. Other meetings are organized around the topic of isotopes in geology, oceanography and atmospheric sciences, for example, ICOG, AGU. However, we agree that AMS should continue to be a strong component at Radiocarbon Conferences, and the attendance of "AMS People" should be encouraged. Some may choose not to attend.

Thus, the Tucson conference was, as usual, rather egalitarian and eclectic. Most colleagues seemed to agree that the meeting structure is not "broke", so why fix it? We already have meetings that focus on specific themes within cosmogenic isotope research, with invited keynote speakers. These are clearly valuable for scientific exchange, but tend to be elitist, and someone with a novel approach may be left off the list of invited speakers. Not everyone is tuned in to global science. Some are intensely interested in the technical minutiae of some particular procedures or in unique sites.

*RADIOCARBON* journal policy is somewhat different for conference volumes than for regular issues. Although we still rigorously peer-review each article, we feel obligated to report what occurred at the meeting. Thus, no meeting papers are rejected based solely on subject matter. If the paper is well-written, contains new data or new interpretations, is scientifically sound and acceptable to reviewers and editors, we publish it.

*Austin Long*

[RADIOCARBON, VOL. 33, NO. 3, 1991, P. 277-282]

**Radiocarbon**

*1991*

# LATE QUATERNARY PTEROPOD PRESERVATION IN EASTERN NORTH ATLANTIC SEDIMENTS IN RELATION TO CHANGING CLIMATE

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**ABSTRACT.** AMS $^{14}$C measurements on pteropod shells from eastern North Atlantic deep-sea cores reveal distinct periods of aragonite preservation during the last 16,000 years. Most preservation spikes coincide with documented periods of climatic change on a scale of $2 \times 10^1$ to $2 \times 10^3$ years.

## INTRODUCTION

Pteropods are fully marine pelagic gastropods that build a shell composed of aragonite. After death of the organism, the shell starts its descent to the sea floor. Because most seawater below the thermocline is undersaturated with aragonite, dissolution of the pteropods starts at an early stage and is enhanced on the sea floor. The final inclusion of well-preserved shells in deep-sea sediments is, thus, an exception (Berner 1977). On the North Atlantic sea floor, pteropod shells are generally absent from depths exceeding 2800 m (Berner 1977; Berger 1978); high productivity may even raise the position of the aragonite compensation depth (ACD) to shallower depths, as is the case along the northeastern continental margin at 45°N (Ganssen & Lutze 1982).

During the North Atlantic Actuomicropaleontology Paleoceanography North Atlantic Project (APNAP) 1986/88 cruises with the *R/V Tyro,* up to 13-cm-thick pteropod oozes were encountered on box core surface sediments from 45°–48°N at depths between 2700 and 3100 m. In addition, several cores contained lenses of fragmented pteropod shells. Species composition was almost monospecific with *Diacria trispinosa* abundantly present. The shells showed a Fe/Mn staining scale from almost white to dark brown. Similar findings were made by Price, Killingley and Berger (1985) on the Rio Grande Rise. We encountered no true "pteropod pavements" south of 45°N, but observed aragonite preservation and Fe/Mn staining in the species *Cuvierina columnella.*

Pilot accelerator mass spectrometry (AMS) $^{14}$C measurements on various staining groups from Core T86/5B, yielded ages between 500 and 3100 B.P. (no correction for reservoir age), indicating that preservation of pteropod shells at this site had been going on for a considerable period of time (Troelstra *et al.* 1987). Apparently, either the position of the ACD in this area was deeper than 2800 m or a particular hydrographic regime, or both, favored aragonite preservation. We discuss this subject in detail elsewhere (Melkert *et al.*, ms).

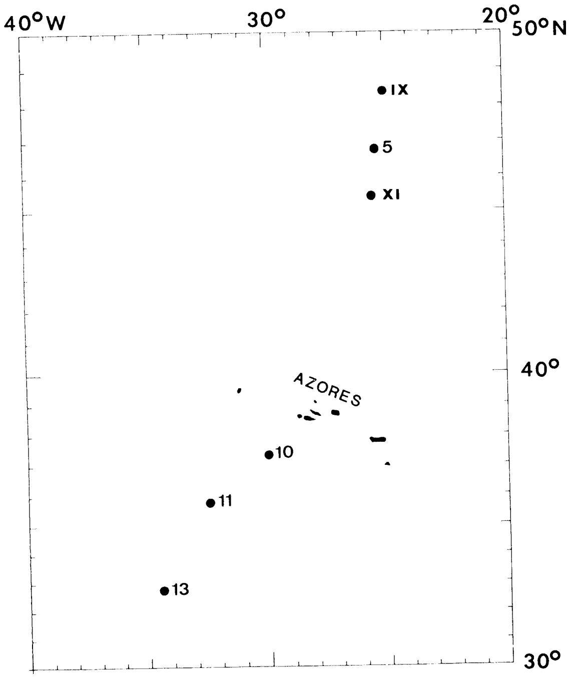

Fig. 1. Location of the box cores from the northeastern Atlantic Ocean discussed in this paper. Arabic numbers refer to box cores taken during APNAP cruise 1986; Roman numbers refer to box cores from APNAP cruise 1988.

We present the results of AMS $^{14}C$ measurements performed on individual pteropod shells from eastern North Atlantic box cores along a traverse, 32°–48°N. Speculations are made on the relation of aragonite preservation to climatic development in this area during the late Quaternary.

## MATERIAL AND METHODS

The material described in this paper derives from six box cores taken in the northeastern Atlantic during the 1986 and 1988 APNAP cruises with the *R/V Tyro* (Fig. 1). Core location, water depth and recovery are indicated in Table 1. Preparation of the aragonitic/calcitic shells followed standard procedures (Hut, Ostlund & van der Borg 1986). In a few cases, the sediments directly underlying the pteropod ooze were dated on bulk planktonic foraminiferal material.

TABLE 1. Station location, water depth and core recovery of northeastern Atlantic material discussed in the text

| Station | Latitude | Longitude | Depth (m) | Recovery (cm) |
|---|---|---|---|---|
| T88/9B | 48°23′N | 25°05′W | 3074 | 28 |
| T86/5B | 46°53′N | 25°21′W | 3121 | 38 |
| T88/11B | 45°24′N | 25°26′W | 2741 | 26 |
| T86/10S | 37°07′N | 30°02′W | 2610 | 36.5 |
| T86/11S | 35°44′N | 32°33′W | 2220 | 14 |
| T86/13B | 32°46′N | 34°42′W | 2992 | 17 |
| DANA41953* | 41°55′N | 32°22′W | 100 (water column) | |

* The DANA sample refers to pteropod net samples, collected 22/6/1931 at a depth of 100 m in the water column.

TABLE 2. AMS $^{14}$C Measurements on material discussed in this paper

| Station no. | UtC no. | Position in core (cm) | Type of organism | $\Delta^{13}$C† (‰) | Age BP‡ |
|---|---|---|---|---|---|
| DANA41953* | 1033 | 100 m (water column) | *Diacria* | 2.50 | 480 ± 50 |
| DANA41953 | 1034 | 100 m (water column) | *Diacria* | 2.10 | 370 ± 70 |
| T88/9B | 1031 | 17–18 | Pter. fragments | 2.03 | 3690 ± 80 |
| T88/9B | 1032 | 18–19.5 | Pter. fragments | 1.90 | 7230 ± 100 |
| T88/9B | 1023 | **1. 0–2 | *Diacria* | 1.10 | 550 ± 60 |
| T88/9B | 1027 | 1. 12–14 | Pter. fragments | 2.03 | 3690 ± 80 |
| T88/9B | 1024 | 2. 0–2 | *Diacria* | 2.40 | 600 ± 100 |
| T88/9B | 1028 | 2. 12–14 | Pter. fragments | 2.21 | 3970 ± 80 |
| T88/9B | 1025 | 3. 0–2 | *Diacria* | 2.30 | 1210 ± 60 |
| T88/9B | 1029 | 3. 12–14 | Pter. fragments | 1.74 | 4970 ± 70 |
| T88/9B | 1026 | 4. 0–2 | *Diacria* | 2.40 | 1870 ± 110 |
| T88/9B | 1030 | 4. 12–14 | Pter. fragments | 1.67 | 8020 ± 110 |
| T86/5B | 423 | 1. 0–1 | *Diacria* | 2.00 | 510 ± 90 |
| T86/5B | 648 | 1. 0–1 | *Diacria* | 2.67 | 790 ± 70 |
| T86/5B | 422 | 1. 0–1 | *Diacria* | 1.99 | 770 ± 110 |
| T86/5B | 421 | 2. 0–1 | *Diacria* | 2.00 | 1140 ± 90 |
| T86/5B | 649 | 2. 0–1 | *Diacria* | 2.41 | 1560 ± 120 |
| T86/5B | 418 | 2. 0–1 | *Diacria* | 2.00 | 1210 ± 110 |
| T86/5B | 650 | 2. 0–1 | *Diacria* | 2.30 | 1540 ± 80 |
| T86/5B | 417 | 3. 0–1 | *Diacria* | 2.18 | 1590 ± 80 |
| T86/5B | 416 | 3. 0–1 | *Diacria* | 2.00 | 1740 ± 110 |
| T86/5B | 415 | 4. 0–1 | *Diacria* | 2.00 | 1870 ± 90 |
| T86/5B | 414 | 4. 0–1 | *Diacria* | 2.00 | 3170 ± 120 |
| T86/5B | 699 | 2–3 | Forams | 1.87 | 1210 ± 80 |
| T86/5B | 700 | 3–4 | Forams | 2.00 | 2700 ± 80 |
| T86/5B | 441 | 1. 1–2 | *Diacria* | 2.00 | 720 ± 110 |
| T86/5B | 437 | 1. 1–2 | *Diacria* | 1.96 | 680 ± 110 |
| T86/5B | 425 | 1. 1–2 | *Diacria* | 2.00 | 710 ± 80 |
| T86/5B | 440 | 3. 1–2 | *Diacria* | 2.00 | 1740 ± 130 |
| T86/5B | 439 | 3. 1–2 | *Diacria* | 2.00 | 1710 ± 110 |
| T86/5B | 438 | 3. 1–2 | *Diacria* | 1.72 | 1690 ± 90 |
| T86/5B | 424 | 4. 1–2 | *Diacria* | 2.00 | 2100 ± 130 |
| T88/11B | 1018 | 1. 0–1 | *Diacria* | 1.80 | 230 ± 50 |
| T88/11B | 1019 | 1. 0–1 | *Diacria* | 2.20 | 620 ± 90 |
| T88/11B | 1020 | 1. 0–1 | *Diacria* | 2.00 | 620 ± 50 |
| T88/11B | 1021 | 3. 0–1 | *Diacria* | 2.70 | 1570 ± 60 |
| T88/11B | 1022 | 4. 0–1 | *Diacria* | 1.80 | 2130 ± 90 |
| T86/10S | 662 | 0–1 | *Diacria* | 0.99 | −480 ± 90 |
| T86/10S | 665 | 0–1 | *Caveolina* | 1.89 | −190 ± 90 |
| T86/10S | 666 | 0–1 | *Clio* | 1.85 | 1070 ± 100 |
| T86/11S | 660 | 1. 0–1 | *Diacria* | 1.94 | 32 ± 60 |
| T86/11S | 661 | 3. 0–1 | *Diacria* | 1.00 | 690 ± 70 |
| T86/13B | 653 | 1. 0–1 | *Diacria* | 1.78 | 10,610 ± 120 |
| T86/13B | 654 | 2. 0–1 | *Diacria* | 1.14 | 7160 ± 80 |
| T86/13B | 735 | 3. 0–1 | *Diacria* | 0.30 | 8170 ± 180 |
| T86/13B | 655 | 4. 0–1 | *Diacria* | 1.46 | 15,600 ± 200 |
| T86/13B | 656 | 5. 0–1 | *Diacria* | 1.30 | 14,600 ± 200 |
| T86/13B | 657 | 1. 0–1 | *Cuvierina* | 1.30 | 10,170 ± 110 |
| T86/13B | 658 | 2. 0–1 | *Cuvierina* | 1.59 | 13,400 ± 300 |
| T86/13B | 659 | 3. 0–1 | *Cuvierina* | 1.31 | 14,140 ± 190 |

*The two DANA samples derive from plankton tows at a depth of 100 m.

**Numbers 1–4 refer to different staining stages of the test of the pteropod species *Diacria trispinosa* and *Cuvierina columnella* (1 = white; 4 = dark brown). The four stages are collected both from the 0–2 as from the 12–14 cm downcore level. Pteropods from the 12–14 cm level are all fragmented.

†$\Delta^{13}$C values measured at the Geology Department, Utrecht.

‡Age in years Before Present from $^{14}$C activity after normalization to $\delta^{13}$C = −25‰. No correction applied for reservoir age.

## RESULTS

Table 2 lists all AMS $^{14}$C measurements performed on our material. In the table, ages are not corrected for reservoir age. The majority of the samples derives from surface sediments, however, preservation horizons downcore were also taken into account (T88/9B). To determine the nature of the surficial pteropod ooze, a foraminiferal sample from T86/5B directly underlying the ooze was measured. Its generally younger age, compared to most ages of the pteropod ooze specimens, indicates that the ooze is a lag deposit. Preservation of the aragonitic shells is strongly enhanced by the Fe/Mn coating.

In order to compare these ages to terrestrial chronologies from plant material, a correction for reservoir age has to be made. To achieve this, we measured pteropods collected during the DANA Expeditions in 1931 (thus before atomic pollution) in plankton nets at a depth of 100 m. AMS $^{14}$C dates on these specimens yielded ages of 370 and 480 B.P. (average of 425 yrs), respectively, which is in good agreement with the theoretical reservoir age model of Stuiver, Pearson and Braziunas (1986). However, strictly speaking, the reservoir age is reserved for pre-industrial samples in contrast with pre-bomb samples. $^{14}$C dilution by fossil fuels is in the order of 10‰ (*ca.* 80 yrs) for North Atlantic surface waters (Druffel & Suess 1983; Bard *et al.* 1988). From Figure 3 in Druffel and Suess (1983), it becomes clear that the period after 1930 accounts for the major part of this so-called Suess effect. In the preceding period, dilution is in the order of 2–3‰ (*ca.* 20 yrs). As our specimens were collected in 1931, we decided not to correct for the entire Suess effect, but only for samples collected before 1930. Hence, in the text and figures all our data (from uncorrected data in Table 2) are corrected by −400 years for reservoir age. The corrected ages were cumulatively plotted in three different time frames: 16,000–2000 B.P. (Fig. 2), the last 2000 years (Fig. 3), and the period A.D. 1500–1900 (Fig. 4). The implications of the plots are discussed below.

## DISCUSSION — PTEROPOD PRESERVATION IN RELATION TO CHANGING CLIMATE

From our data set, it becomes clear that aragonite preservation is a recurrent feature during the last 16,000 years in the eastern North Atlantic. Figure 2 shows that, on a longer time scale, preservation periods occurred from 15,200–13,000, 10,300–9700, 8000–6000 and 4500–2700 B.P. The first two events correspond to Termination 1A and 1B, respectively (*cf.* Bard *et al.* 1987); a worldwide preservation peak centered around 14,000 B.P. has also been postulated by Berger (1977). The

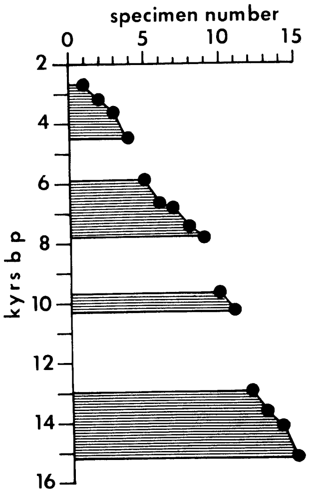

Fig. 2. Cumulative plot of 15 pteropod specimens *vs.* time (16,000–2000 B.P.). $^{14}$C ages corrected for reservoir age by −400 years. Shaded areas indicate periods of aragonite preservation.

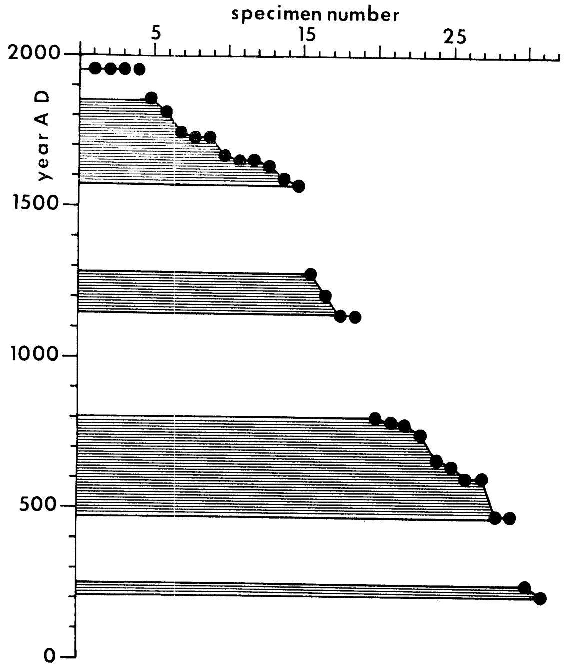

Fig. 3. Cumulative plot of 31 pteropod specimens *vs.* time (the last 2000 years). $^{14}C$ ages corrected for reservoir age by −400 years. Shaded areas indicate periods of aragonite preservation.

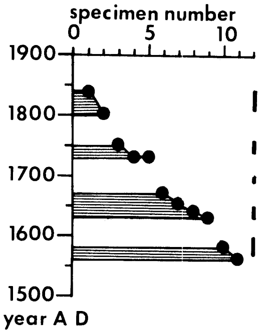

Fig. 4. Cumulative plot of 11 pteropod specimens *vs.* time (the Little Ice Age). $^{14}C$ ages corrected for reservoir age by −400 years. Shaded areas indicate periods of aragonite preservation. Vertical bars mark the cold periods as established by Serre-Bachet and Guiot (1987).

third period approximates Termination 1C (Berger 1990); Kassens & Sarnthein (1989) mention enhanced aragonite preservation around 7000 B.P. in the equatorial Atlantic. The first three preservation spikes are thus strongly correlated to the deglaciation steps following the last glacial maximum. Also, for the period 4500–2700 B.P., a link to climate fluctuations can be made considering major climatic changes at about 4200, 3600 and 2500 B.P. reported by Frenzel (1975).

On a limited time scale (Fig. 3), distinct intervals of aragonite preservation can be observed from A.D. 200–250, 480–800, 1150–1180, 1560–1840 and Recent. The period, A.D. 1560–1840, nicely matches the Little Ice Age, which is characterized by various cold spells between 1570 and 1840 (Serre-Bachet & Guiot 1987). The work of these authors is based on reconstructions of the mean summer temperature by tree-ring densitrometric measurements from the Alps and the Mediterranean region. Plotting our data from this period in an even narrower time frame (Fig. 4), periods of pteropod preservation show a remarkable fit with the cold periods established by Serre-Bachet & Guiot (1987), *i.e.*, A.D. 1570–1600, 1630–1650, 1690–1700, 1740–1760 and 1810–1840, although we are aware that, considering the accuracy of the $^{14}C$ technique and the corrections applied for the reservoir age, a little wishful thinking cannot be excluded.

## CONCLUSION

In summary, conditions leading up to pteropod preservation prevailed during intervals of climatic change, such as the Last Glacial/Holocene transition, the period 4500–2700 B.P. and the Little Ice Age. We conclude that other intervals of aragonite preservation within the last 2000 years also may have been caused by similar short-term periods of climatic change.

## ACKNOWLEDGMENTS

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# SHELL HASH DATING AND MIXING MODELS FOR PALIMPSEST MARINE SEDIMENTS

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**ABSTRACT.** The dating of palimpsest marine sediments using broken shell fragments (shell hash) is considered to be a necessary but unreliable technique because of the mixed age of the fragments. An analysis of geological mixing models and radiocarbon data on shell hash from sandy sediments on the southeast Australian coast and shelf are used to examine the possibility for simulating the depositional processes, and thus, to better understand the age structure of the deposits.

## INTRODUCTION

Classic mixing models devised for sediments accumulating in the deep sea and on allochthonous shelves (Berger & Heath 1968; Guinasso & Schink 1975; Carney 1981) are not readily applicable to wave-dominated environments with palimpsest sediments, such as the southeast Australian shelf. Here, sediment transporting and reworking mechanisms are likely to be "episodic," in the sense used by Dott (1983); mixing rates almost everywhere are very much greater than accumulation rates (which, in some cases, are negative), and contemporary sediment sources, sinks and transport pathways are poorly defined. Thus, it is difficult to apply conventional theories of mixing and strata formation as, *e.g.*, in the Washington Shelf study by Nittrouer and Sternberg (1981).

Late Quaternary sediments in coastal and nearshore environments in southeast Australia are composed, in large part, of marine sands – mainly quartz and biogenic carbonate. The carbonate is made up of broken fragments (the tests of marine organisms), and has been extensively dated by $^{14}C$ methods to determine the time of deposition of the enclosing sediment (Thom, Polach & Bowman 1978; Thom *et al.* 1981; Chapman *et al.* 1982; Thom 1984). This material is not used by preference, but because nothing else of a more *in-situ* nature is available. Commonly, the samples submitted for dating are made up of hundreds of biogenic carbonate fragments (shell hash), each presumably with a different age and history of reworking and transport – an extreme case of the stratigraphic disordering described by Flessa, Cutler & Meldahl (1989). Clearly, the reported age is some average figure that cannot precisely correspond to the time the enclosing sediment was deposited. That bulk $^{14}C$ samples are made up of an admixture of different-aged shell fragments has recently been confirmed by Walbran *et al.* (1989), who used accelerator mass spectrometer (AMS) techniques to date individual fragments of *Acanthaster planci* in sediment cores from the Great Barrier Reef. Figure 1 shows the relationship between the $^{14}C$ date on bulk carbonate sand and the AMS ages for individual grains located close by. If the carbonate sand has the same age structure as the AMS samples, then bulk $^{14}C$ dates represent a strongly skewed spread of individual ages that cluster within 400 years of the reported age, but include a proportion that are considerably older. Other indications that reported $^{14}C$ dates on bulk shell samples are distorted (age-shifted) come from presently active depositional surfaces that return shell hash ages of 1000–2000 years B.P. Nielsen and Roy (1982) discussed this mixing phenomenon and attempted, with partial success, to calculate a correction factor to compensate for the incorporation of old shell.

Despite this mixing problem, the broad patterns shown by hundreds of $^{14}C$ dates from a number of Holocene depositional environments in southeast Australia show sensible trends. Patterns of deposition fit geological models of how, *e.g.*, coastal sand barriers and estuarine flood-tide deltas form (Fig. 2), and dated sequences in cores rarely display the stratigraphic disorder described by

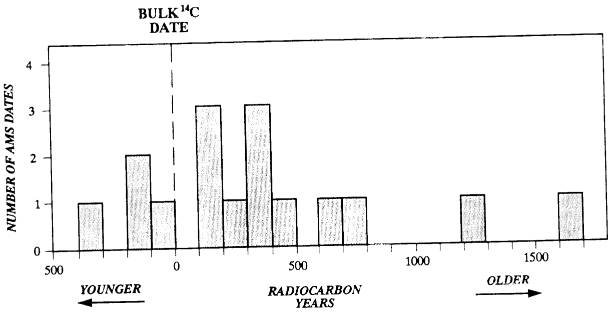

Fig. 1. Histogram showing discrepancies between $^{14}C$ ages of bulk carbonate sand samples (in three cores) and AMS dates on individual fragments of *Acanthaster planci* in the sand. All AMS samples are within 15 cm of the bulk samples, and average sedimentation rates in the cores are in the order of 1.0–2.0 mm $yr^{-1}$. Based on data from the Great Barrier Reef in Walbran *et al.* (1989).

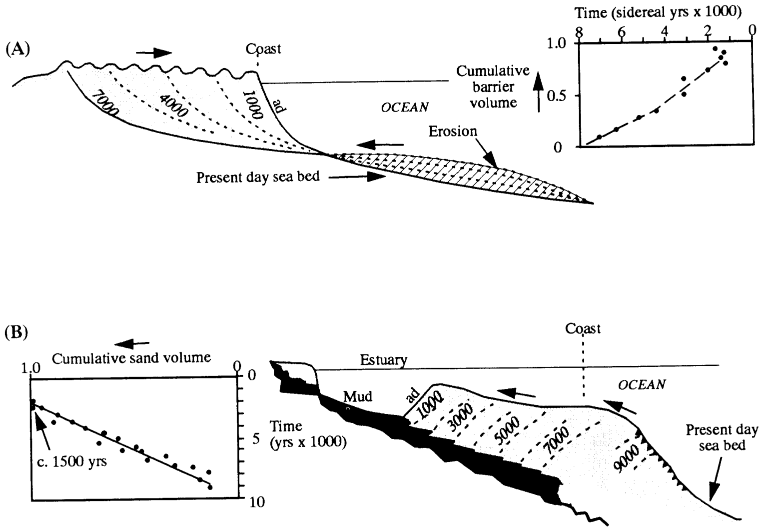

Fig. 2. Diagrammatic cross-sections of sandy coastal depositional sequences: (A) prograded barrier and (B) estuarine flood-tide delta, both with presently active depositional surfaces (ad); arrows show directions of sediment supply and progradation. In each environment, $^{14}C$-dated shell-hash samples (•) document regular patterns of volumetric change. Based on data from the Tuncurry barrier (Chapman *et al.* 1982) and the Port Hacking tidal delta (Roy 1984).

Flessa, Cutler and Meldahl (1989) and Cutler and Flessa (1990). Is it possible to improve our understanding of late Quaternary depositional processes by unraveling the mixing problem? The following is a preliminary attempt to devise a model that describes physical mixing of shell fragments in sandy sediments on a moderately high-energy coast that is undergoing extensive reworking.

## THE MIXING MODEL

If a single shell dies and is immediately buried by accumulating sediment, its $^{14}C$ age (corrected to sidereal years) should indicate the time of deposition of the enclosing sediment layer. In coastal and shelf depositional environments, the closest approach to these passive conditions is in deep estuarine basins, where mud slowly settles from suspension, and buries shells living and dying on the bed of the estuary. But even here, biological activity exists and, given the slow rates of sedimentation (0.1–0.5 m $yr^{-1}$, according to Roy (1984)), there is a good chance that the test will be bioturbated upwards or downwards into younger or older sediment layers (Roy & Crawford 1984). In these types of settings, the mixing mechanisms are quite well understood (Carney 1981); mixing depths have been measured using radioactive tracers (Carpenter, Peterson & Bennett 1985), and the processes have been successfully modeled (Wheatcroft *et al.* 1990). In higher energy environments, such as beaches, shorefaces, tidal inlets and the inner shelf, physical reworking by waves and currents, as well as by biological processes, ensures an even greater degree of mixing. Here, factors such as episodicity and event magnitude, recurrence interval, recovery time and preservation potential (Dott 1983) are poorly understood, and limit our ability to apply conventional mixing models.

The elements of the geological mixing model proposed here are:

1. Periodic disturbance of the sea bed to variable depths and at various frequencies, creating a near-surface zone of reworking or mixing in the sediment pile
2. Progressive addition of the tests of newly dead organisms (contemporary shell) to the sea bed at a semiconstant rate over geological time spans
3. A slow but constant rate of breakdown of older shell in the zone of reworking due to abrasion, decay, *etc.*
4. Addition or subtraction of clastic sediment (deposition or erosion) that shifts the zone of reworking upwards or downwards through the sediment pile
5. Addition of old shell fragments eroded from elsewhere and transported to a new site of deposition.

Mixing in the reworked zone occurs during storms, as sand waves and ripples migrate over the sea bed, and during quiet periods, by bioturbation. Geological studies by Hudson and Roy (1988) show that the depth of reworking on the open coast decreases offshore with increasing water depth. Depths range from many meters on the beach face to 20 cm or so on the mid-shelf. Since deep reworking can be expected to occur much less frequently than shallow reworking, it is likely that the long-term mixing process can be expressed as some type of exponential function (inset in Fig. 3), the actual values and shape of which are site-specific. This concept is similar to the multiple mixed layers mentioned by Nittrouer and Sternberg (1981: Figs. 14, 15).

Three mixing scenarios of increasing complexity are considered below:

*Model A. In-situ* reworking with addition of no new sediment except for contemporary shell

*Model B (1). In-situ* reworking as in Model A with addition of new sediment (but containing no old shell) at a constant rate

*Model B (2). In-situ* reworking as in Model B (1) accompanied by slow erosion of the sea bed

*Model C.* Same depositional scenario as for Model B, but with the addition of old shell hash derived from elsewhere.

Model A is illustrated in Figure 3 by a vertical segment into the sea bed, which also represents a graph showing the relative proportions of different-aged shell hash in the reworked zone. At time $t_1$, the parent sediment, 2000 years old, has been reworked to depth ‘d’, and a proportion of younger shell averaging 1000 years old has been added. Although, in reality, the younger shell

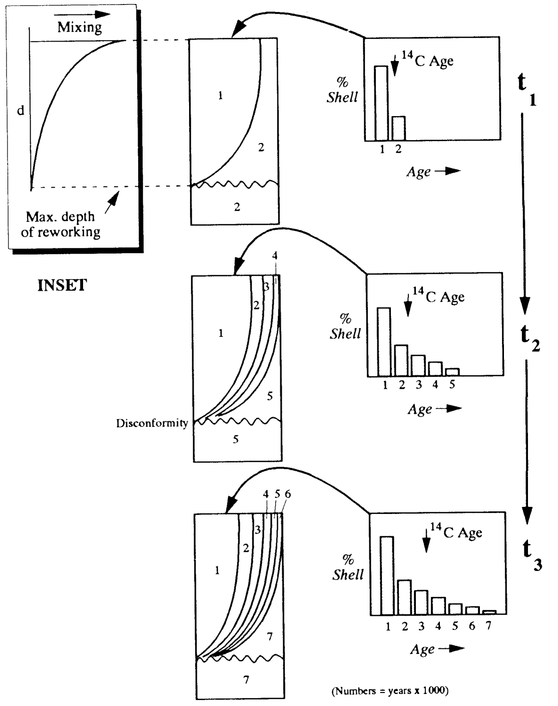

Fig. 3. Mixing Model A shows *in-situ* reworking of parent sediment to depth 'd', below the sea bed and the progressive addition of contemporary shell (averaging 1000 yrs old). The inset depicts a hypothetical mixing function that defines the depth of reworking and the vertical distribution of young shell in the mixed zone. The parent sediment is assumed to be 2000 years old at time $t_1$, and 7000 years old at $t_3$, 5000 years later. Histograms at each time step indicate the relative proportions of various-aged shell fragments on the contemporary sea bed. Note that the measured $^{14}$C age of the sea bed becomes progressively older (age-shifted) because of upward mixing of old shell.

fragments are distributed throughout the reworked zone, the mixing function predicts that most will occur in its upper part, and least near its base. The relative proportions are indicated by a concentration profile in Figure 3, time $t_1$.

At times, $t_2$ and $t_3$, 3000 and 5000 years later (Fig. 3), progressive mixing can be depicted figuratively as successive increments of younger and younger shell. Since the amount of old shell is expected to decrease with time due to abrasion, decay, *etc.*, the "slices" representing older shell proportions in Figures 3 and 4 are thinner than for younger shell. A disconformity is soon created at the base of the reworked zone. The overall effect is that the surface sediments appear older than the contemporary age of the sea bed, whereas the sediment within the reworked zone appears younger than the parent sediment. Figure 4 illustrates other effects of *in-situ* reworking. An age structure is created within the mixed zone that becomes older downwards and, despite the original age of the parent sediment, has $^{14}$C ages that are confined to mid- to late Holocene. A similar trend to that shown in Figure 4 could also be expected if the sea bed was slowly eroding rather than static (Model B (2)).

Thus, *in-situ* reworking is an alternative explanation of what normally would be viewed as slow upward accretion under postglacial stillstand conditions. The age pattern shown in Figure 4 has been noted in regard to the inner shelf sand sheet in southeast Australia (Colwell & Roy 1983;

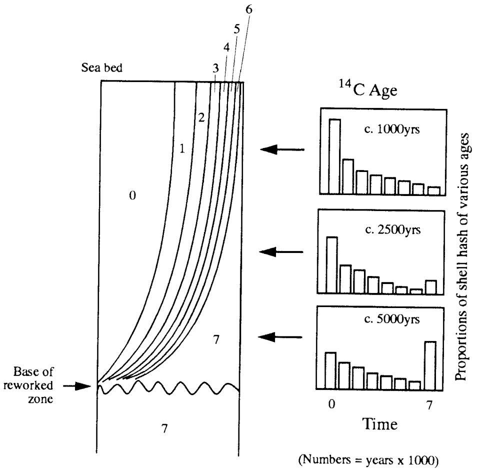

Fig. 4. Illustration of the way in which a regular age structure (age increasing downwards) can be created by *in-situ* reworking of a parent sediment 7000 years old. With, say 26,000-year-old parent sediment, this trend is similar and the $^{14}$C ages only slightly older. It is speculated that the relative proportions of the various aged added-shell fractions would progressively decrease from 0–7 (7000) years.

Thom & Roy 1985) and also on the upper surface of the shelf sand bodies off the south Sydney coast (Roy 1985).

In Model B (1), deposition is superimposed on *in-situ* reworking (Model A), but without the introduction of old shell hash. Figure 5A shows four, 1000-year time steps in which the zone of reworking is progressively raised upwards as sediment accumulates. Unlike Model A, a disconformity does not form in this sediment sequence, nor do surface sediments become progressively older with time. The faster the sedimentation rate, the closer the measured $^{14}$C age of the sea bed approaches its contemporary age (*i.e.*, zero). Figure 5B illustrates how dependent the $^{14}$C age of a shell-hash sample is on the proportions of different-aged shell fractions. Because of the decay of radioactive $^{14}$C, the contribution by older shell to the measured $^{14}$C age is much less than that of more recent shell. For layer 'x', in the subsurface, it is interesting to note that mixing causes its real age (shown in brackets in Fig. 5A) to be underestimated by $^{14}$C dating. The discrepancy increases with time even though the layer is not being actively reworked during later time steps $t_3$ and $t_4$.

For slower sedimentation rates, the discrepancy between true and measured ages in the subsurface becomes larger, and is presumably a maximum for *in-situ* reworking with no added sediment). Conversely, for shallower depths of reworking, such as would be expected under quieter conditions in deeper water, the discrepancy between true and measured ages decreases, even though the rate of sedimentation remains unchanged.

Figure 6 shows apparent ages of surface sediments collected in various water depths off Sydney. Although there is some scatter, the trend of increasing age with increasing depth is what would be predicted if sedimentation rates decreased, and *in-situ* reworking becomes more intense as the offshore sea bed deepens. This accords with what is known about the geological setting (Roy 1984), but other variables, such as depth and intensity of reworking and age of parent sediments, probably also play a role.

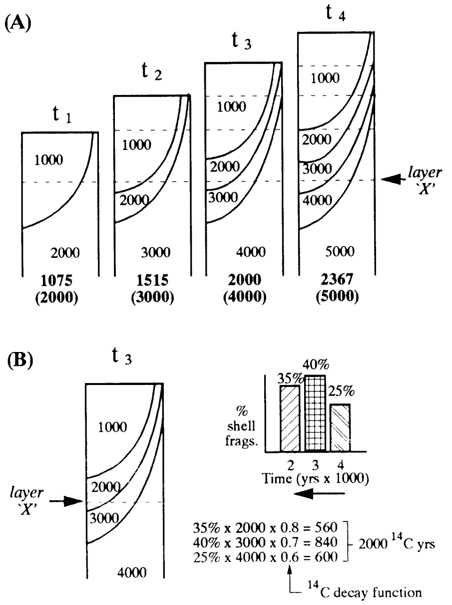

Fig. 5. Mixing Model B showing: (A) progressive sedimentation at four 1000-year time steps. Accretion causes the zone of reworking to move upwards, and no disconformity forms in the sediment pile. Using the method described in (B), below, $^{14}$C ages of shell hash in layer "x" are calculated at each time step (age of parent sediment in brackets); (B) a method for determining the $^{14}$C age of shell hash in layer "x" (at time $t_3$), given that the proportions of the various-aged shell fractions are known. The $^{14}$C decay function is only approximate.

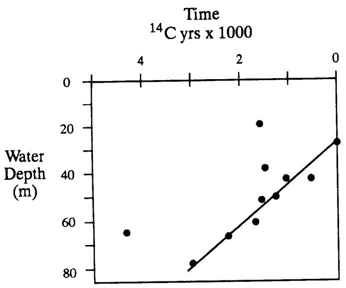

Fig. 6. Radiocarbon ages of shell hash in surface sediments, sampled with a small pipe dredge offshore from Sydney, show a tendency to increase with increasing water depth (from Roy 1985).

In a depositional (accreting) sedimentary environment, if old shell fragments are added to the sea bed and mixed downwards with contemporary shell hash, the overall age of the reworked zone will become older. This is the situation for Model C, which has not yet been simulated. Interestingly, the addition of old shell in Model C reduces the discrepancy predicted in Model B (1) between the actual time of deposition and the measured $^{14}$C age of the biogenic material. This exemplifies the complexities created by mixing of materials from diverse sources, and highlights the challenge of simulating "real" conditions as described in Model C.

## CONCLUSIONS

With growing sophistication of the various radiometric dating technologies, there is heightened awareness of the range of likely errors that can influence age determinations. However, it seems that the chemical factors leading to dating errors are better understood by analytical laboratories than are the physical environmental factors that are the concern of the field scientist. The theoretical models presented here are a tentative first step towards better understanding physical mixing in sandy sediments. Underlying assumptions need to be refined and quantified, but clearly, the approach is amenable to computer simulation (*e.g.*, Cutler & Flessa 1990). There may also be applications to other techniques of dating such as thermoluminescence (TL). Future lines of research may include cross-calibration of $^{14}$C dates against other measurements (*e.g.*, TL and electron spin resonance (ESR)), but direct measurements of individual shell fragments by AMS is not considered to be a practical approach at this time, because of the cost of dating very large numbers of samples.

## ACKNOWLEDGMENTS

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# RADIOCARBON IN SEAWATER AND ORGANISMS FROM THE PACIFIC COAST OF BAJA CALIFORNIA

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**ABSTRACT.** Radiocarbon was measured in dissolved inorganic carbon (DIC) and living organisms collected off the west coast of Baja California in October 1980. Samples from three locations were examined. $\Delta^{14}C$ of DIC at the southernmost station was higher than those further north, which reflects reduced upwelling in the southern region. Crabs and anchovies had $\Delta^{14}C$ values significantly lower than surface DIC $\Delta^{14}C$, indicating the incorporation of 'older', sediment-derived carbon sources from their diets. Comparisons are made between our DIC $\Delta^{14}C$ measurements and those obtained during other cruises and at a coastal site, from 1959 through 1987. Two distinct time histories of DIC $\Delta^{14}C$ are apparent for the post-bomb period: 1) a lower $\Delta^{14}C$ curve for sites close to the coast influenced by enhanced coastal upwelling; and 2) a higher $\Delta^{14}C$ curve for sites further offshore within the California Current.

## INTRODUCTION

Bomb radiocarbon was produced in the stratosphere during the late 1950s and early 1960s. As a result of its production, atmospheric $^{14}CO_2$ levels increased by nearly two times in the northern hemisphere (Nydal & Løvseth 1983). By exchange of $CO_2$ between atmosphere and surface ocean waters, bomb radiocarbon has slowly infiltrated the upper ocean. Time histories of radiocarbon in the surface ocean during the post-bomb period have allowed us to examine various short-term processes that control carbon exchange in this layer: 1) gas exchange with the atmosphere; 2) vertical mixing with subsurface waters that generally contain lower radiocarbon activities; and 3) lateral mixing with water masses of distinct $^{14}C$ signatures.

We report $\Delta^{14}C$ results for the coastal region off Baja California. When compared with similar measurements from the coastal and offshore locations for the entire post-bomb period, a pattern emerges that reveals two distinct $\Delta^{14}C$ trends. The area within *ca.* 150 km of the coast contains significantly lower levels of bomb $^{14}C$, due to dilution by 'old', upwelling waters. Locations offshore have consistently higher $\Delta^{14}C$ values than coastal regions examined during the same calendar year, which is expected, due to reduced upwelling in the California Current.

## MATERIAL AND METHODS

Samples reported here were collected during a surface film cruise (SF-2) on the *R/V New Horizon* in October 1980. For a description of the chemical and biological characteristics of the sea-surface films and near-surface waters studied in this region, the reader is referred to Williams *et al.* (1986).

Surface seawater samples (190 L) were collected from 2 m depth, using a Jabsco pump mounted on the main deck. A subsurface water sample was collected from 200 m at Site 2 by making 6 casts of a 30-L Niskin bottle. Each water sample was stored in a 210-L polyethylene-lined steel drum, to which 1 g of mercuric chloride had been added to poison biological activity. To avoid the possibility of contamination by $^{14}C$-labeled compounds that were being used aboard ship, the drums were returned to the La Jolla Radiocarbon Laboratory for extraction.

DIC was stripped from each water sample using standard methods (Linick 1980). One liter of concentrated sulfuric acid was added, and the drum was heated to 50°C . A small volume of air (10–20 Ls) above the seawater solution was recirculated, using a peristaltic pump, and the air was bubbled through a 1-L solution of 15 N $NH_4OH$ and 1 M $SrCl_2$ for four hours. Most of the ammonia was decanted, and then the solution was heated under vacuum to remove residual ammonia, leaving a dried precipitate of strontium carbonate. Acid digestion was performed with 2 N HCl, and the evolved $CO_2$ was collected. $CO_2$ was converted to acetylene gas *via* a lithium carbide intermediate (Linick 1975).

Three biological samples were collected from 0–1 m depth in Thurloe Bay on the night of 8 October 1980. Collections were made with a hand net from the *R/V New Horizon*'s main deck. Samples were frozen and brought back to the laboratory for radiocarbon analysis. Inorganic carbon was removed from each sample initially using 2 N HCl. The samples were dried and burned in a stream of medical-grade oxygen at 600°C . The resultant $CO_2$ was converted to $C_2H_2$ *via* $Li_2C_2$. The smallest sample (LJ-5459 Crabs) was counted as $CO_2$.

Samples were counted for two, 2-day periods in quartz (2.2 and 2.5 L) or stainless steel (0.4 and 1.0 L) gas proportional beta counters and at 900 mm Hg and 25°C . The crabs (LJ-5459) sample was counted for two 6-day periods in a 0.20-L copper counter.

Samples were measured relative to 95% of NBS Oxalic Acid I activity, corrected to a $\delta^{13}C$ of –19.0‰ (PDB). Sample activity was corrected to a $\delta^{13}C$ of –25.0‰. Results are reported in the standard $\Delta^{14}C$ notation (in per mil, Stuiver & Polach 1977). Uncertainties given are one-sigma deviation errors based on statistics of sample, standard and background activities.

## RESULTS

The $\Delta^{14}C$ results of DIC and biological organisms collected on the SF-2 cruise are reported in Table 1. Figure 1 shows sampling locations. The first DIC (Site 1) sample had a surface $\Delta^{14}C$ value of +109 ± 8‰, and was located just south of the U.S./Mexico border, *ca.* 18 km offshore. Site 2 was located *ca.* 140 km offshore of Baja. The surface DIC sample was +113 ± 4‰ in $\Delta^{14}C$, and the sample at 200 m depth was –5 ± 4‰. Site 3 was 4 km outside of Thurloe Bay (5 km from shore), and the surface DIC $\Delta^{14}C$ value was +133 ± 4‰.

The $\Delta^{14}C$ results from three samples of organisms collected from the surface waters of Thurloe Bay were all similar within the reported error. A large anchovy measured +72 ± 7‰, numerous small anchovies (~10 cm long) were +79 ± 7‰, and numerous pelagic crabs (*Pleuroncodes planipes*, 1–2 cm long) were +58 ± 17‰.

## DISCUSSION

Waters off the California and Baja coasts are influenced by marked upwelling in spring and early summer, induced by northerly winds. By October, upwelling all but ceases (Sverdrup, Johnson & Fleming 1942). As a result, there is little seasonal variation in temperature in the California coastal region.

Seawater $\Delta^{14}C$ results appear to increase as one goes further south along the Baja coast (Table 1). To the south are waters of lower salinity and higher temperature. Density profiles indicate less communication between surface and subsurface waters in the southern region than in waters to the north. Thus, we expect to find higher $\Delta^{14}C$ values in the surface waters to the south.

TABLE 1. Radiocarbon Measurements for Samples Collected on SF-2 Cruise (October 1980)

| C Pool | LJ-# | Site # | Collection date | Location | Depth (m) | $\Delta^{14}C$ (‰) | $\delta^{13}C$ (‰) |
|---|---|---|---|---|---|---|---|
| DIC | 5258 | 1 | 4 Oct 1980 | 31°59.8′N<br>117°12.0′W | 2 | +109 ± 8 | +0.3 |
| DIC | 5260 | 2 | 5 Oct 1980 | 28°38.5′N<br>117°04.3′W | 2 | +113 ± 4 | +3.4 |
| DIC | 5261 | 2 | 5 Oct 1980 | 28°37.8′N<br>117°04.3′W | 200 | −5 ± 4 | −1.2 |
| DIC | 5259 | 3 | 10 Oct 1980 | 27°33.0′N<br>114°52.3′W | 2 | +133 ± 4 | −1.9 |
| Anchovy (large) | 5457 | 3 | 8 Oct 1980 | 27°37.3′N<br>114°50.1′W | 0–1 | +72 ± 7 | −18.3 |
| Anchovies (10 cm) | 5458 | 3 | 8 Oct 1980 | 27°37.3′N<br>114°50.1′W | 0–1 | +79 ± 7 | −18.3 |
| Crabs *Pleuroncodes planipes* (1–2 cm) | 5459 | 3 | 8 Oct 1980 | 27°37.3′N<br>114°50.1′W | 0–1 | +58 ± 17 | −19.5 |

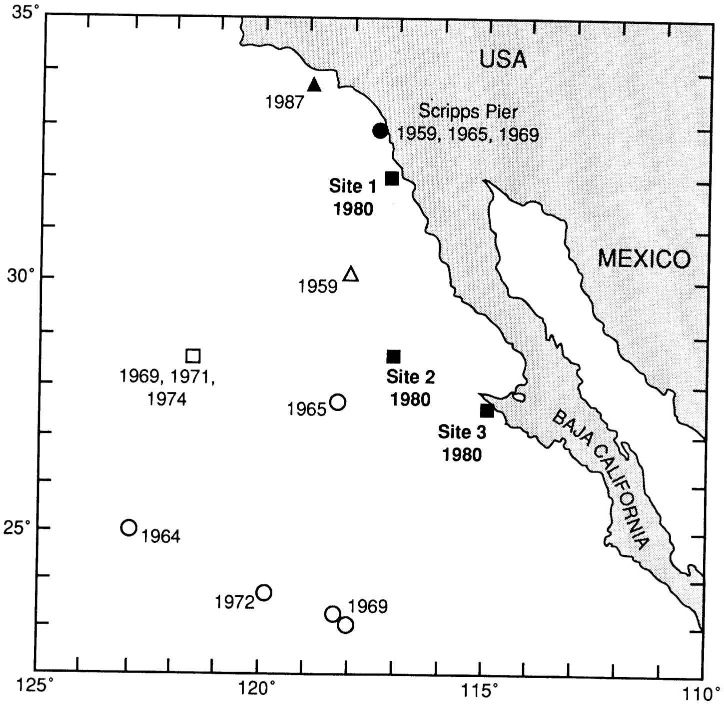

Fig. 1. Map of sampling locations aboard the *R/V New Horizon* on SF2 cruise (■). Also shown are locations and year(s) of collection for samples reported by other investigators, plotted in Figures 2 and 3.

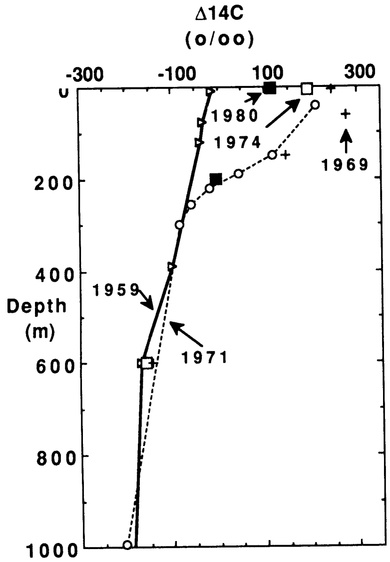

Fig. 2. Depth profiles of $\Delta^{14}C$ from our Site 2 in 1980 (■) and from the GEOSECS test (1969, +), GOGO I (1971, ○) and GEOSECS (1974, □) stations (28.5°N, 121.5°W) 450 km offshore of Baja California (Östlund & Niskin 1970; Roether 1974; Östlund & Stuiver 1980). A depth profile taken in 1959 (▷) reported by Bien, Rakestraw & Suess (1965), from 30.0°N, 118.0°W, is shown for comparison.

Higher $\Delta^{14}C$ values were reported for samples collected from a location 450 km offshore from Baja. This station, at 28°30'N,121°44'W, was occupied as a GEOSECS test site in September 1969 (Östlund & Niskin 1970). It was reoccupied as GOGO I site in November 1971 (Roether 1974), and during GEOSECS again as Stn. 347 in June 1974 (Östlund & Stuiver 1980). $\Delta^{14}C$ depth profiles from these studies and from Site 2 are shown in Figure 2. A profile taken in 1959 reported by Bien, Rakestraw & Suess (1965) for a station 160 km offshore of Bahia Colnet are plotted for comparison in Figure 2. Our two $\Delta^{14}C$ values from 2 m and 200 m near the coast of Baja were significantly lower in $\Delta^{14}C$ than those observed offshore at the GEOSECS/GOGO site, despite the fact that our samples were taken several years later. Dilution of nearshore water due to upwelling is the likely reason for these low coastal $\Delta^{14}C$ values near the coast. Also, horizontal advection of bomb radiocarbon from the north to the offshore GEOSECS site *via* the California Current cause overall higher $\Delta^{14}C$ values (Broecker & Peng 1980).

Time histories of $\Delta^{14}C$ in surface waters off the southern California/Baja coast reveal overall lower values in nearshore regions. In Figure 3, $\Delta^{14}C$ DIC values for nearshore (within 150 km) and offshore (150–500 km) locations are plotted *versus* the year of collection. $\Delta^{14}C$ DIC values rose more quickly at the offshore locations, owing to the reduced upwelling that occurs further from shore. This offshore $\Delta^{14}C$ trend resembles that observed in the mid-gyre region of the North Pacific Ocean, as reconstructed by annual coral bands (Druffel 1987) (Fig. 3). The time history of $\Delta^{14}C$ from Galapagos corals (Druffel 1981) is also shown in Figure 3 as an example of a record influenced by intense upwelling. From the bomb $^{14}C$ records, it is apparent that upwelling near the Baja coast is not as intense as it is near the Galapagos Islands in the eastern equatorial Pacific, though it is significant enough to support increased levels of nutrients and primary production.

Low $\Delta^{14}C$ values found for the three biological samples are likely due to feeding on sediment-derived carbon and on organisms that contain low $^{14}C$ activity carbon. Pearcy and Stuiver (1983) and Williams, Druffel and Smith (1987) found reduced $^{14}C$ activities for meso- and abyssopelagic organisms in the North Pacific, owing at least in part to incorporation of 'old' carbon from mid-water regions.

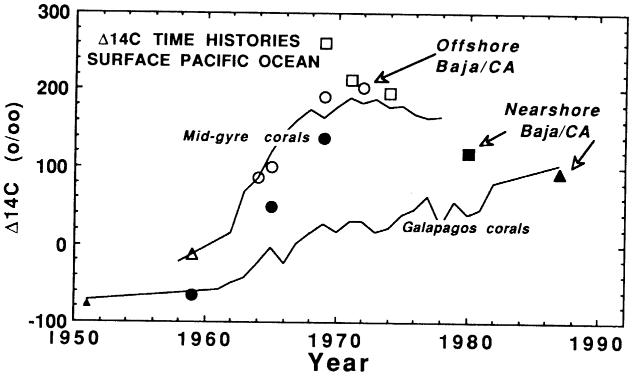

Fig. 3. Time histories of $\Delta^{14}C$ from DIC and shells from > 150 km offshore of Baja California (Δ - Bien, Rakestraw & Suess 1965; ○ - Linick 1975; □ - Östlund & Niskin 1970; Roether 1974; Östlund & Stuiver 1980) and the coastal region <150 km from shore (■ - this study; ▲ - Berger, Taylor & Libby 1966, Robinson & Thompson, 1981; ● - Scripps pier, Linick 1975; ▲ - Williams *et al.* 1991). For comparison, $\Delta^{14}C$ records from annually banded corals from the Galapagos Islands (1°S, 90°W) and French Frigate Shoals (24°N, 166°W) are also plotted (Druffel 1981, 1987).

The $\Delta^{14}C$ results reported here add to the data base that documents the input of bomb-produced isotopes to the oceans. The continued examination of these quantities allow us to view oceanic properties, such as circulation, on much shorter time scales than would have been allowed, if these spike tracers had not been introduced. It is the silver lining on the cloud of nuclear weapons testing.

## ACKNOWLEDGMENTS

Our thanks go to Sheila Griffin, who assisted in the shore-based radiocarbon analyses. We appreciate the help of the crew of the *R/V New Horizon*. This work was supported by National Science Foundation Grant Nos. OCE-7917653 and OCE-8111954. WHOI Contribution No. 7845.

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[RADIOCARBON, VOL. 33, NO. 3, 1991, P. 297–301]

# LITHIUM CONTAMINATION IN AMS MEASUREMENTS OF $^{14}C$

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**ABSTRACT.** High count rates of lithium ions in an AMS measurement system for $^{14}C$ were traced to the lithium content in the quartz tubes used in the graphitization of the samples. The lithium contamination was nearly eliminated by the use of borosilicate glass reaction tubes at a lower reaction temperature. The ion beam current and the measurement precision of the isotope ratio were not affected.

## INTRODUCTION

Since the initial work of Nelson, Korteling and Stott (1977), AMS laboratories have observed variable amounts of lithium and "di-lithium" (two $Li^{2+}$ ions entering the detection system simultaneously) in the $^{14}C$ spectra of AMS measurements, when using the even charge states of carbon from a tandem Van de Graaff accelerator. Both species of detected lithium are injected into the accelerator as a negative $Li_2$ ion at mass 14. The molecule is dissociated at the terminal stripper, and Coulomb repulsion separates the two atomic ions. A fraction of possible repulsion geometries allows the two ions to enter the detector simultaneously. More of the separated ions are on projections that bring only one of the pair to the detector.

The M/q analysis of the positive ions eliminates these lithium ions in AMS systems using the +3 or +5 charge states of carbon. We prefer to analyze +4 carbon ions to obtain higher system efficiency at our 6–7 MV operating voltage. At these energies, the lithium contamination is easily discriminated from the voltage pulses due to true $^{14}C$ counts in a multiple-anode gas ionization detector. However, bursts of lithium ions have occasionally caused count rates in excess of 25,000 cps. Our data-collecting software applies livetime corrections at 0.3- to 0.5-second intervals, and such bursts do not affect the overall measurement to more than 0.2‰. The more usual rates of 500–2000 cps have no effect on the analyzed data. However, the variability of the lithium content among different samples drove us to discover its source, and led us to a simplification of our graphitizing procedures.

## LITHIUM CONTAMINATION

Our first difficulties with di-lithium were traced to a jar of activated charcoal, which was used in testing the CAMS spectrometer before graphite-production facilities were complete. Perhaps the charcoal was activated in an alkali wash that contained large amounts of lithium. Also, our original bench for loading the AMS samples was close to the area used for coating filaments with lithium hydride for use in a direct extraction ion source. Better handling protocols prevent this lithium from entering the AMS sputter source. However, the detector spectra continued to show varying lithium contamination in prepared samples.

Typical spectra from a single anode are shown in Figure 1, for samples with little lithium and for those with contamination. The lithium peak in most spectra is small and constant for repeated measurements of the same sample. In other cases, the lithium is intense and does not change over

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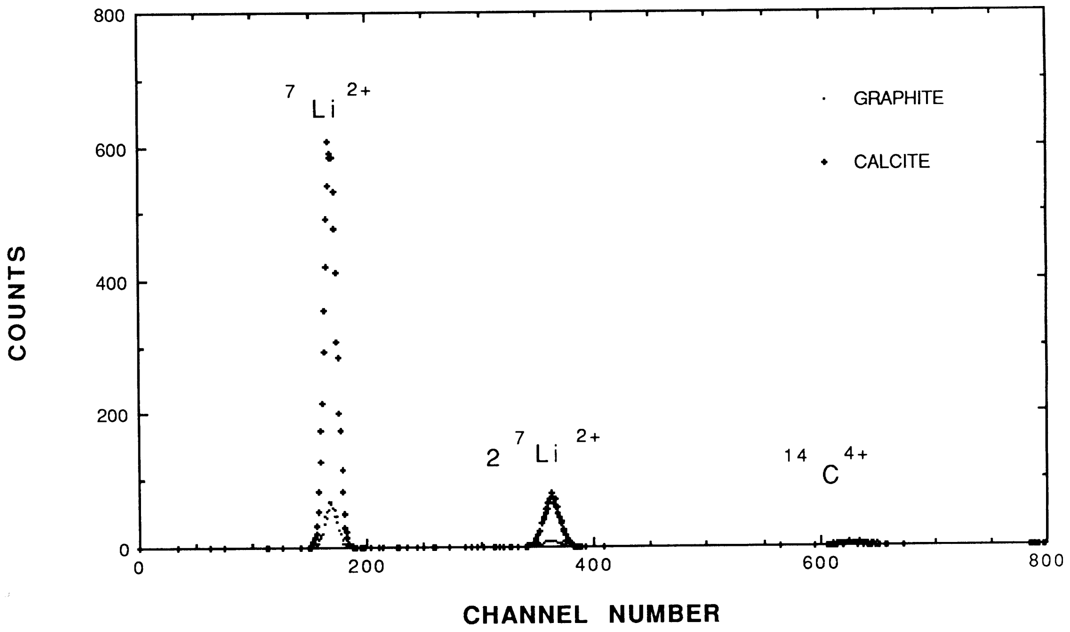

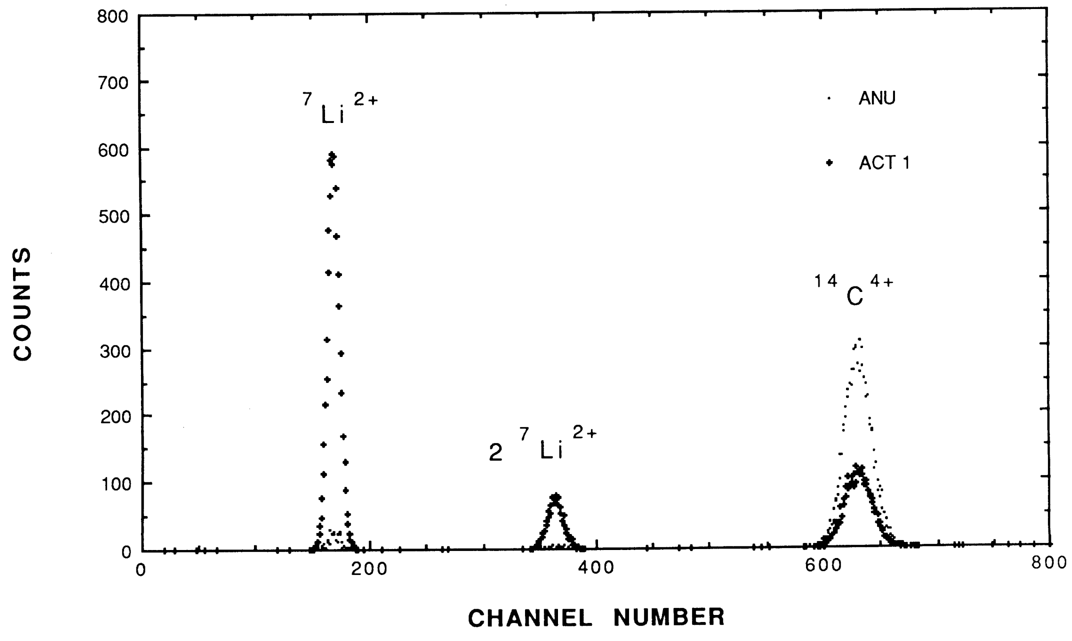

Fig. 1. Energy deposition spectra are shown for 4 samples, 2 of which (ACT-1 and Calcite), have lithium contamination in the prepared graphite. The prepared graphite made from ANU sugar and the unprepared geological graphite show low levels of lithium contamination, which may arise in the ion source rather than in the graphite preparation. In all spectra, the first peak arises from $^{7}Li^{2+}$, the second peak is caused by two simultaneous $^{7}Li^{2+}$, and the third peak is due to $^{14}C^{4+}$. All spectra are normalized to the counts in 100 seconds.

the several measurements. Another behavior shows a moderate or low lithium contamination that suddenly becomes very intense. The intense contamination may quickly disappear or last through several measurements. The lithium is not associated with the ion source itself, or as a contaminant in the sputtering cesium, since all behaviors are observed in neighboring samples placed in the ion source in quick succession. The cobalt catalyst used in the graphitization process does not produce lithium beams when it is placed directly into the ion source. We do not observe an increase of lithium in graphites stored for over a year. However, we find that geological graphite increases lithium emission by a factor of five over a period of several hours, indicating that memory effects in the ion source can contribute a small amount of lithium. The ratio of di-lithium to lithium varies from 1:1.5 to 1:15, and a ratio of 1:4 is most common. The ratio is not an apparent function of ion current or system control settings.

Graphites readily form intercalation compounds with alkali metals (Hennig 1959), and the continuous emission of lithium from some samples indicates its uniform distribution, which must arise chemically in the preparation of filamentous graphite. No lithium compounds have sufficiently high vapor pressures to survive the cryogenic purification and transport of the gases produced by sealed-tube combustion (Vogel, Nelson & Southon 1987). Thus, the contamination must arise during the graphitization, which involves only the catalyst, the purified $CO_2$, hydrogen and the reaction vessel. The catalyst and the gases have been ruled out, but one possible source of lithium is the fused quartz of the reaction tube itself.

We observed that samples that contained small chips of quartz (a result of not fire-polishing the open end of a series of reaction tubes) produced large and fluctuating amounts of lithium contamination: up to 120 times the lithium found in geological graphite. The samples showed points of light during sputtering, where the non-conducting quartz chips were heated in the cesium beam. Such spot heating causes observable fractionation (Vogel, Southon & Nelson 1987). Many glasses, including the precursors of high-temperature glasses, are composed of silicate mixed with sodium (and hence, other alkali) compounds. These elements are chemically bound in most glasses, but can exist in high-temperature glasses as interstitial elements left from the etching process (Nordberg 1944). The quartz chips are an obvious source of the sporadic lithium contamination, but the uniformly distributed lithium is not as easily understood. High-temperature glasses, such as fused quartz and Vycor, are more porous than borosilicate glasses (Eitel 1966). We hypothesize that lithium migrates out of the quartz reactor tubes in the vacuum of the nearly complete reaction at temperatures over 600°C. Initial baking of the quartz tubes in air to 900°C does not eliminate this lithium. Variations in lithium between samples may be related to initial gas pressures or to detailed temperature histories of the tubes, but we have no data to firmly establish this. Instead, we decided to test the hypothesis by using a different glass for the reactors.

## BOROSILICATE GLASS REACTION TUBES

Although we measured more lithium in borosilicate glass than in fused quartz (secondary ion mass spectrometry using a Kameca IMS-3F, D. Phinney, personal communication), we investigated whether the contamination could be reduced by using borosilicate glass for the reaction tubes. The resulting graphite samples have 20 to 50 times less lithium than those produced in quartz, and only 2 to 10 times the lithium found in geological graphite. The use of borosilicate glass tubes for the reactors requires only slight modification of our preparation protocols, and produces filamentous graphite of the same quality as that from quartz reactors.

Regardless of its relationship to the amount of lithium in the spectra, the use of borosilicate glass tubes is attractive, from the standpoint of reduced cost and effort in the production of AMS sam-

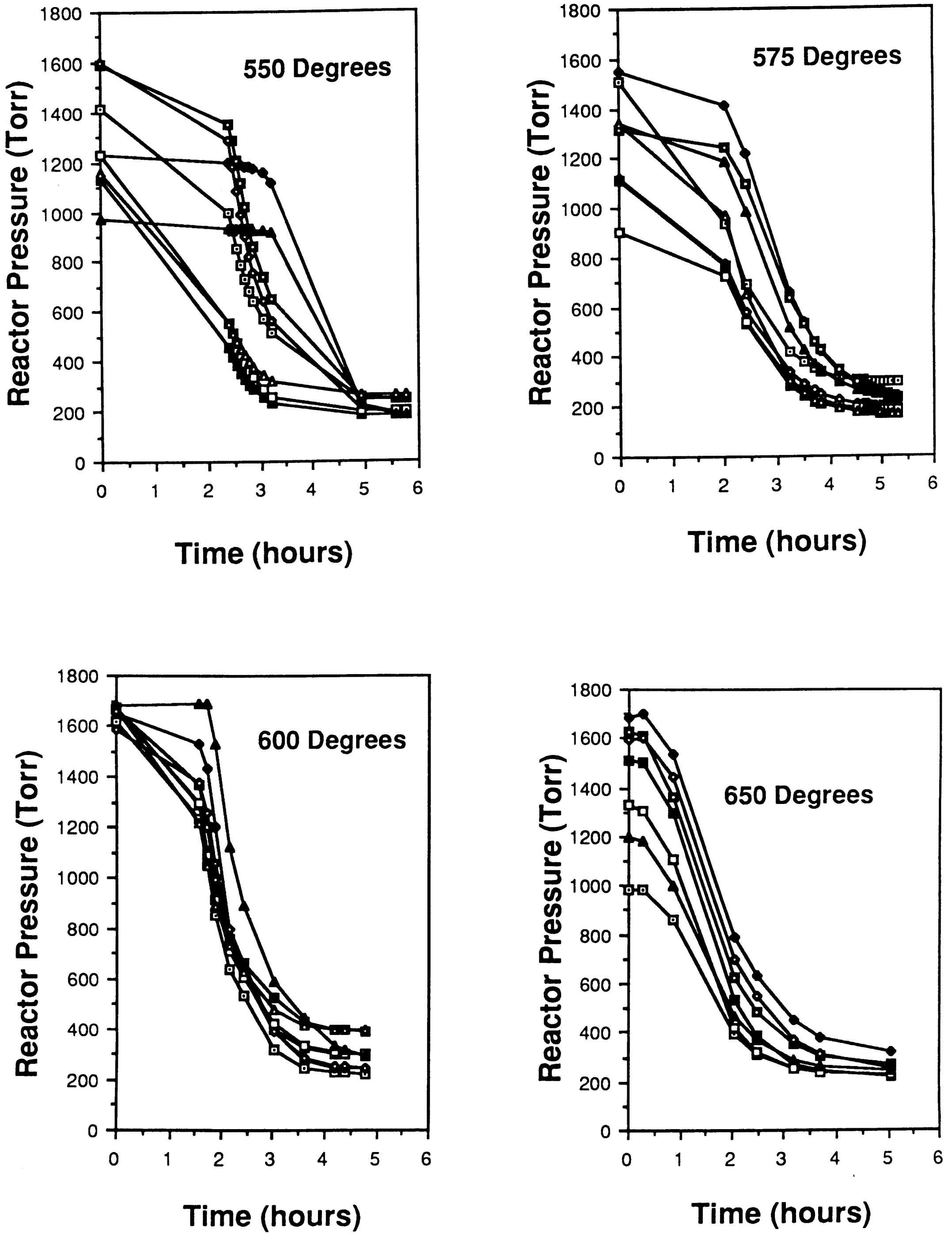

Fig. 2. The pressure *versus* time plots are shown for 4 different reaction temperatures in 8 different reactors. The asymptotic approach of the gas pressure to a constant low level is taken as an indication of the completion of the reaction. Many reactions are complete after 4 or 5 hours, but reactions at the coolest temperature, 550°C, occasionally do not proceed for 3 or 4 hours.

ples. The quartz tubes were either purchased from professional glassblowers at considerable expense, or else produced 'in house' with less uniformity in quality. We now use standard 6 mm × 50 mm biological culture tubes, which are available from several manufacturers for approximately 10¢ each. We purchase clean, sealed packages of the tubes, which are used once before disposal. The tubes are available with both thin walls or thick walls. The thin-walled tubes soften and partially collapse during heating, and the temperature must be reduced to a maximum of 575°C for the thick-walled tubes. At this temperature, we still observe occasional softening of the tubes.

Graphs of gas pressures in eight reactors at different temperatures show (Fig. 2) the times at which the pressures approach a constant value, taken as a sign that the reaction is complete. Contrary to the evidence of Kromer *et al.* (1987), we see an increase in the time required for the reaction to proceed to completion from even these small changes in operating temperature. Our reaction vessels are much smaller, however, and gas diffusion or pressure effects may dominate. We also observe slight differences in the reaction times between reactors and on different days. At 575°C, the reaction is usually done in five hours, and is almost always complete in six hours. Note that at 550° C, several of the reactions do not even begin to precipitate carbon for almost three hours, and we do not allow our temperatures to decrease to that level. Samples smaller than 100 $\mu$g can take considerably longer than six hours to finish, however, and we continue to use quartz reactors at higher temperatures for them. Other than the lower temperature, all other operating parameters have been outlined previously (Vogel, Nelson & Southon 1987; Vogel, Southon & Nelson 1987).

## CONCLUSION

We have found that disposable, inexpensive, borosilicate glass culture tubes can be used reliably at lower temperatures to replace quartz reaction tubes, when producing filamentous graphite for AMS sample preparation. The culture tubes are uniform in manufacture and do not chip during handling. Glass chips in a sample produce high amounts of lithium ions, but the frequency of these chips is greatly reduced by using the glass tubes. Similarly, small pieces of glass wool are sources of lithium in a sample, and sample holders should not be cleaned with glass filter paper or glass wool. The lithium that was uniformly distributed through graphite samples, and that had become a contamination in a large fraction of our samples, has been eliminated.

## ACKNOWLEDGMENTS

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[RADIOCARBON, VOL. 33, NO. 3, 1991, P. 303-315]

# CUELLO: RESOLVING THE CHRONOLOGY THROUGH DIRECT DATING OF CONSERVED AND LOW-COLLAGEN BONE BY AMS[1]

*I. A. LAW[2], R. A. HOUSLEY[3], NORMAN HAMMOND[4] and R. E. M. HEDGES[3]*

**ABSTRACT.** It is well known that $^{14}$C dating of fossil bone with seriously depleted protein levels, or bone that has been consolidated with preservatives, can produce erroneous results. In the tropics, warm and moist soil conditions lead to constant reworking of organic matter and add to the danger of bone contamination. Because of this, $^{14}$C dating of preservative-impregnated bone from such areas has rarely been successful. We report here a set of AMS dates on both unconsolidated animal bone and polyvinyl acetate/polyvinyl alcohol (PVA/PV-OH) impregnated human burials from the Maya site of Cuello, Belize. The steps needed to purify the samples are described, together with details on the use of qualitative infra-red (IR) spectra as a means of assessing sample purity.

## INTRODUCTION

The site of Cuello, situated on the eastern margin of the rain-forest zone of the Maya Lowlands in northern Belize (18°05′N, 88°35′W), is well known for its long sequence of occupation spanning the Formative period (notionally 2000 B.C.–A.D. 250) of Mesoamerican prehistory (Donaghey *et al.* 1976; Hammond 1980; Pring & Hammond 1982). A Classic period (A.D. 250–900) occupation also exists, and recently, some evidence for subsequent Postclassic activity has been found (Hammond, Housley & Law 1991).

The dating of the Preclassic at Cuello has been controversial and widely debated (Hammond *et al.* 1979; Coe 1980; Marcus 1983, 1984; Hammond 1984; Andrews 1986; Andrews & Hammond 1990). For most Maya sites, the traditional chronology was based on archaeological evidence, particularly on the ceramic typology. Historical dates were derived from monumental inscriptions placing the Classic period in the first millennium A.D., and dates for the preceding Preclassic (or Formative) period were constructed from best guesses in the pre-radiocarbon era (*cf.* Smith 1955). Even when radiocarbon dating became available and was applied to the Preclassic, few dates were run. Further, the absence of a discrepant historical chronology muted the impact of tree-ring calibration curves when they were introduced in the 1960s. For most Mesoamerican prehistorians, radiocarbon ages and calibrated dates were equivalent and comparable data, leading to some curious misinterpretations.

The survival of the "guesstimate" chronology for the Maya Preclassic meant that any differing radiocarbon chronology, and/or the use of calibrated dates, which would, in most cases, extend the sequence back in time, would be controversial; this was amply demonstrated in the case of the Preclassic sequence at Cuello.

Following the first excavations at Cuello in 1975–1976, when a previously unknown early ceramic phase (Swasey) was defined stratigraphically below the widely-documented Mamom and Chicanel sphere occupations, radiocarbon dates on wood charcoal from Preclassic contexts of all three ceramic periods were made by the laboratories at the University of California, Los Angeles (UCLA) and Cambridge (Q) (Hammond *et al.* 1976, 1977). These dates indicated a "long" chronol-

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ogy (Fig. 1) with the Swasey phase from *ca.* 2500 to *ca.* 1300 cal. B.C. The Lopez Mamom phase lasted from 1300 cal. B.C. to *ca.* 450 cal. B.C., and the Cocos Chicanel from 450 cal. B.C. to the beginning of the historically defined Classic period in A.D. 250, this last span agreeing with the accepted estimated duration of Chicanel. The two laboratories showed good internal consistency and good agreement (to within one standard deviation), when both stratigraphically adjacent and divided single samples were dated. Hammond *et al.* (1979) saw no reason to reject the radiocarbon chronology, despite the fact that, on archaeological grounds, it disrupted some preconceived notions about the existence of an occupation in the formally defined Early Preclassic period prior to 1000 B.C. in the Maya Lowlands. Although the close similarity to Middle Preclassic pottery had been noted, as had the distinction from Early Preclassic ceramics from other regions of Mesoamerica, the assignment of the Swasey material to the Early Preclassic was believed necessary on chronological grounds. Some scholars accepted this (*e.g.*, Lowe 1978), whereas others (*e.g.*, Coe 1980: 34–35; Marcus 1984) believed that the ceramic similarities had priority, and that a Middle Preclassic affiliation was in order, despite the radiocarbon dates.

Subsequent dating of charcoal samples from the 1979–1980 excavation seasons by the radiocarbon laboratories at Cambridge (Andrews & Hammond 1990: Table 1) and La Jolla (Linick 1984) pro-

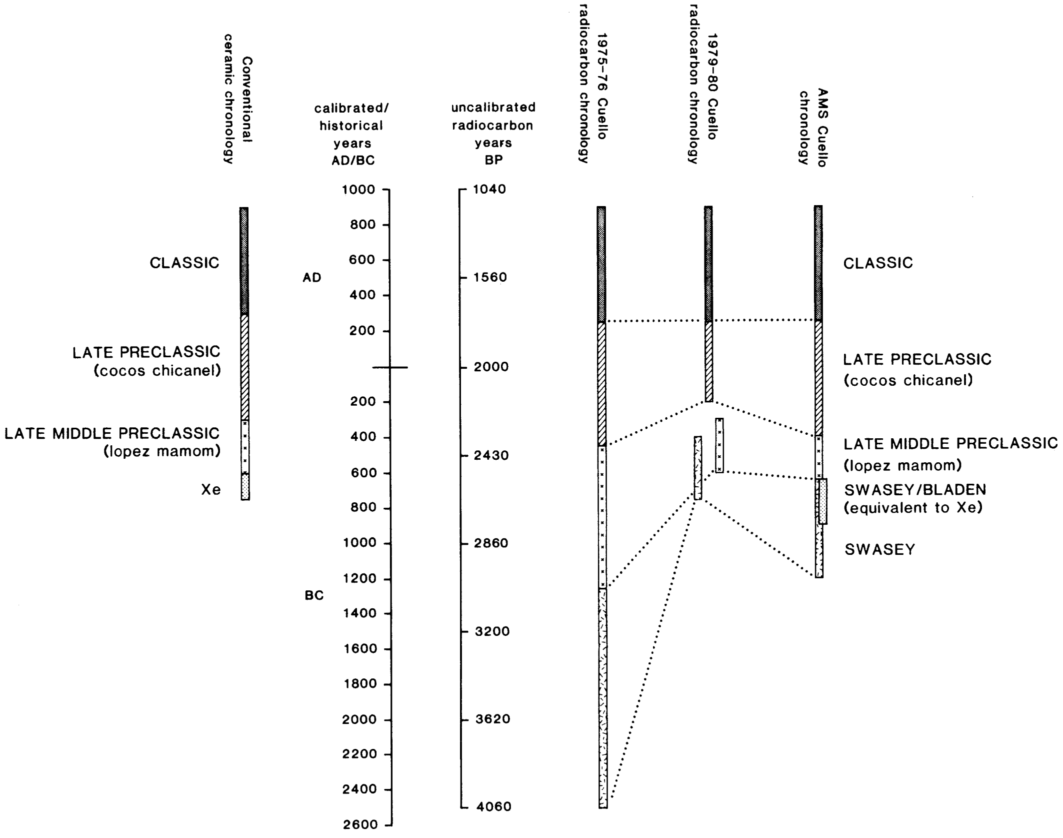

Fig. 1. Conventional (ceramic) chronology for Mesoamerica compared with the "short" and "long" radiometric $^{14}$C chronologies of the Cambridge (Q), Los Angeles (UCLA) and La Jolla (LJ) laboratories, and the AMS chronology proposed here. Courtesy of the Research Laboratory for Archaeology and the History of Art, Oxford University.

duced a second, discrepant chronology (Fig. 1), which indicated a much shorter period of occupation. Again, the laboratories agreed, but no answer could be found as to why the second suite of dates "compressed" the sequence into a shorter time period. The suggestion that anciently burned wood was recycled into later deposits, giving erroneously early dates for Swasey, but also becoming progressively masked by larger quantities of contemporary carbon as the occupation of Cuello developed (Andrews & Hammond 1990), is not of itself implausible. Yet it does not explain why the 1975–1976 and 1979–1980 excavations of adjoining areas, with visibly continuous stratigraphy, should yield contrasting suites of dates, nor the origin of the ancient burning.

The contrast in chronologies, which demonstrably were neither the result of excavation techniques and personnel (the same from year to year) nor of laboratory procedures (since two laboratories produced similar results in each case) remains a mystery. Yet the dating of Cuello needed to be resolved – the "long" chronology had been cogently challenged, but some of the radiocarbon ages obtained on the "short" chronology were far too late even for the conventional "guesstimate" time scale of the Maya Preclassic.

A fresh approach was indicated, based on dating short-lived material from the relevant occupation layers. Since maize kernels, the most abundant such remains, were also important for paleoethnobotanical studies and could not be sacrificed for dating, although one experimentally dated fragment yielded a satisfactory result (Hammond & Andrews 1990: Table 1, Sample AA-458), we decided to date human bone from burials. The contemporaneity of the bones with their archaeological context was unquestioned, and the associated grave goods linked the human remains directly to the cultural sequence. Because of the poor condition of the bone after several millennia in a leaching tropical environment, insufficient collagen remained for conventional $^{14}$C dating. Thus, AMS dating was employed.

In light of the problems described above, and of cogent arguments that the ceramic chronology proposed by Hammond *et al.* (1979) was too early (Marcus 1984), we made an attempt, in 1985, to date human bone collagen from Cuello by AMS, in order to resolve the controversy. Two Preclassic human skeletons were sampled (Burial 62, Context [F110] of the Swasey phase, the earliest interment at the site and Burial 5, Context [76/137] of the Bladen phase (now reassigned by Andrews & Hammond (1990) to early Lopez Mamom)) and dated, using the pretreatment methods outlined in Gillespie, Hedges & Humm (1986). The dates obtained (OxA-361: 2460 ± 80 and OxA-362: 2390 ± 90 B.P., respectively; Gowlett *et al.* 1986: 122) failed to resolve matters: they were statistically identical at one sigma, despite the substantial vertical stratigraphic gap between the burials. Both dates were also later than expected, OxA-361 by over a millennium when compared to the established "long" chronology, OxA-362 by several centuries, although the 800–400 cal. B.C. calibration "plateau" complicated the problem, as did the low level of preserved collagen. On the basis of the dates reported here, Burial 62 (OxA-361) should have yielded a date of *ca.* 2840 B.P.; reevaluation of the stratigraphic position of Burial 5 (Andrews & Hammond 1990) now renders OxA-362 fully acceptable.

We think these initial AMS dates could be in error for the following reasons:

1. Both bones contained only 5% of their original collagenous protein (using the Gillespie *et al.* (1986) method – subsequent research showed that only 0.17% could be extracted and purified as bone amino acids – see Hedges and Law (1989), and references therein, for fuller discussion).
2. Constant reworking of organic matter in tropical climates makes the probability of environmental contamination high. The effect of such contamination increases as the

collagen content of the bone decreases.

3. Both samples had been consolidated with a PVA/PV-OH emulsion during excavation, although this was not recognized at the time as being important, and thus, was not emphasized to the laboratory.

Once these factors were appreciated, a series of bones from Cuello burials was selected for another dating attempt, and for testing new pretreatment procedures developed specifically to overcome such problems. Infra-red (IR) spectra of final and intermediate fractions from the consolidated bones were recorded to monitor the effect of the various purification steps, and for consideration when assessing the accuracy of the dating results.

## PRETREATMENT STRATEGY

"Control" samples of animal bone from clearly defined Preclassic contexts at Cuello were included in the experiment. These came from Contexts [Q114] and [Q146], occupation deposits of the Lopez Mamom phase (650–400 cal. B.C.), recycled as fill in a construction event at the beginning of the Cocos Chicanel phase (400 cal. B.C.–A.D. 250), the dating of which was approximately the same on the conventional "long" and "short" chronologies (see Fig. 1). The bone had not been consolidated or conserved in any way, and served to check that our pretreatment could overcome the problems associated with high levels of environmental contamination and low levels of collagen. (The level of collagen used here is defined as the weight of total amino acid obtained from hydrolysis of 'gelatin' prepared by the methods outlined below. In our experience, the amino-acid composition of such a preparation is generally collagenous, at least when the collagen level is greater than 5–10 mg $g^{-1}$ bone).

Two additional human burial samples, from Burials 10 [F7] and 62, were treated as a pilot study aimed at assessing the effectiveness of our laboratory pretreatment on conserved, low-collagen bones. For this reason, three dating fractions were isolated from each bone: 1) total acid-insoluble fraction ("crude collagen"); 2) aqueous, pH3, extract of this ("crude gelatin"); 3) purified gelatin ("ion-exchanged gelatin"). Qualitative IR spectra were used to estimate the purity of the fractions and, hence, the reliability of the radiocarbon ages obtained.

Samples followed from Burials 123 [F251] and 7 [17 F232], which we treated on the basis of the results obtained from Burials 10 and 62, with only one dating fraction (amino acids from purified gelatin) being isolated from each bone. However, we isolated sub-samples of gelatin and ion-exchanged gelatin as intermediates in the process, and recorded qualitative IR spectra.

A purely archaeological inquiry was also added to the experiment. The superficial layers at Cuello included pottery of the Classic period (A.D. 250–900) and some evidence for Postclassic activity. Animal bones, fragments of unidentified large mammal – cervid most likely, from four of these contexts were dated (Q44, Q23, Q74, Q109). Of these, the latter two were from the latest known architectural features, and might thus indicate how long occupation at Cuello had continued. All of the samples were free of consolidant, so IR spectra were not recorded on intermediate fractions.

## EXPERIMENTAL DETAILS

*Precleaning.* All bones were cleaned mechanically ("shot blasted") before being crushed to a fine powder in a liquid-nitrogen-cooled "Spex" freezer mill.

*Extraction of Consolidants.* Bones from Contexts [F7] and [F110] were leached sequentially with hot distilled water, methanol (at 60°C), and acetone at room temperature. Leachates were evaporated to dryness, but no extractable components were observed. The bones from Contexts [F251] and [F232] were extracted with acetone under reflux for several hours, but again, there was little evidence that this process removed adsorbed consolidants.

*Demineralization and Extraction of "Collagen."* The dried bone powders were demineralized using the semi-automated continuous-flow method described in Law and Hedges (1989). Briefly, bone powder is retained within a glass and PTFE flow cell, through which solutions are passed sequentially. In this way, the bone is demineralized with 0.5 M hydrochloric acid to obtain the total acid-insoluble residue. This is leached with 0.1 M sodium hydroxide, and then rinsed thoroughly with distilled water, to produce the "crude collagen" fraction.

*Extraction and Purification of Gelatin.* Gelatin is extracted from the crude collagen by adjusting the pH of the water within the cell to 3.0 with dilute hydrochloric acid. The cell is then sealed, and heated at 100°C overnight. This process causes collagenous protein to dissolve, leaving the largely water-insoluble polymers, such as polyvinyl acetate (PVA), as a residue, which can be removed by filtration. When dry, the filtrate constitutes the "crude gelatin" fraction. The crude gelatin can be purified further, in some cases, by ion exchange. The gelatin is applied in solution at pH3 to a column of BioRad AGMP-50 resin, and can be desorbed in 1.5 M $NH_4OH$ (Law & Hedges 1989; Hedges & Law 1989).

*Hydrolysis of Purified Gelatin and Ion Exchange of Amino Acids.* The dried sample is hydrolyzed in 6 M hydrochloric acid, at 105°C overnight, using 1 mL of acid per 15 mg of protein. When cool, the hydrolyzate can be decolorized, using activated charcoal or BioBeads SM-2 resin, before being filtered and dried under vacuum to remove excess hydrochloric acid. After redissolving in water, the sample is desalted by ion exchange on Dowex 50W-X8 resin (eluted with $NH_4OH$). Pretreatment yields are recorded in Table 1.

TABLE 1. Pretreatment Results

| Burial | Context | Weight of bone used (g) | Fraction isolated* | Yield ($mg \cdot g^{-1}$) | % wt yield |
|---|---|---|---|---|---|
| – | [Q114] | 7.5 | 1 | 8.9 | 0.12 |
| – | [Q146] | 7.5 | 1 | 10.0 | 0.13 |
| 10 | [F7] | 2.8 | 2 | 10.7 | 0.38 |
| 10 | [F7] | 2.8 | 3 | 7.1 | 0.25 |
| 10 | [F7] | 2.8 | 4 | 5.3 | 0.19 |
| 62 | [F110] | 2.6 | 2 | 19.2 | 0.74 |
| 62 | [F110] | 2.7 | 3 | 5.5 | 0.20 |
| 62 | [F110] | 2.1 | 1 | 3.6 | 0.17 |
| 123 | [F251] | 1.7 | 1 | 5.6 | 0.33 |
| 7 | [17 F232] | 1.6 | 1 | 17.25 | 1.08 |
| – | [Q44] | 1.06 | 1 | 95.0 | 8.96 |
| – | [Q23] | 1.45 | 1 | 60.3 | 4.16 |
| – | [Q74] | 1.3 | 1 | 43.0 | 3.31 |
| – | [Q109] | 3.0 | 1 | 0.53 | 0.02 |

*Key: 1 = amino acids from ion-exchange gelatin
2 = crude collagen
3 = crude gelatin
4 = ion-exchange gelatin

*Infra-Red Spectroscopy.* Qualitative IR spectra of the isolated fractions were obtained by grinding together 1 mg of sample and 20 mg of KBr with an agate pestle and mortar, pressing this into a disk, and recording the spectrum against a KBr blank on a Perkin-Elmer 1420 double beam spectrophotometer.

## RESULTS AND DISCUSSION

We dated the samples using the Oxford AMS system, the operation of which has been discussed elsewhere (Hedges *et al.* 1989). Table 1 records pretreatment yields. Tables 2–3 present data from the IR spectra; Table 4 shows the $^{14}$C measurements and the calibrated age ranges.

## INFRA-RED SPECTROSCOPY IN DETECTING CONTAMINATION OF PROTEIN BY CONSOLIDANT

IR spectroscopy is used widely in the identification of synthetic polymers. To a lesser extent, it has been used in the study of protein structures (Timasheff & Susi 1966). Most synthetic polymers give diagnostic "fingerprint" spectra, and positive identifications can be made when the spectrum of the unknown compound matches that of a known standard material. With extracts from archaeological samples, complex spectra may be obtained, *e.g.*, when mixed polymer emulsions have been used, or when the bone has undergone several conservation treatments with different materials. Some polymer preparations "age," leading to cross-linking reactions (Horie 1987), and altering the spectra obtained. For the present samples, we know that only one type of consolidant has been used – Vinamul 6815. This is a PVA/PV-OH emulsion that contains other minor constituents, and which is known to become insoluble with time through cross-linking reactions (J. Spriggs, personal communication 1989). The main IR absorption bands for PVA and polyvinyl alcohol (PV-OH) are shown in Table 2, and the presence of these peaks in the spectra of protein samples can indicate contamination by consolidant.

Collagen and gelatin share a characteristic IR spectrum, shown in Figure 2 and interpreted in Table 2. Diagenesis of protein eventually leads to changes in the IR spectrum, and these can lead to confusion, especially when contamination by a consolidant is also suspected.

*The Preclassic Burial Samples.* Table 3 illustrates the general trend found during the purification of proteins and peptides extracted from the consolidated human bone samples. It is clear that the "crude collagen" fractions are contaminated with PVA and PV-OH, although protein amide bands are also present. Gelatinization and filtration remove absorbance features associated with the consolidant from all samples except Burial 62; in this sample, the main contaminant is PV-OH. It is difficult to be sure that PVA has been removed, as the acetate C=O absorbance may be masked by peptide bands, especially in the samples from Burials 7 and 123. However, the peptide bands at 1725 cm$^{-1}$ are relatively sharp, and this would not be the case if they were overlapped by the 1740 cm$^{-1}$ acetate absorbance. It is worth noting that the spectrum for Burial 10 shows this sample to be particularly pure, a slight enhancement of the 1240 cm$^{-1}$ band being the only sign of contamination.

Confirmation that the 1725 cm$^{-1}$ peak is due to carboxylic acid groups is found when the gelatin fractions are ion-exchanged, and isolated as the ammonium salts, $-COO^{-}NH4^{+}$. Salt formation causes the -COOH band to disappear, with the simultaneous appearance of a sharp absorbance peak at *ca.* 1400 cm$^{-1}$, due to the $-COO^{-}$ anion, and this is observed with the present samples (Fig. 3B). The similarity between the spectra of the peptized samples (Fig. 3A), with that obtained by the partial hydrolysis of modern collagen (Fig. 2B), proves that the -COOH groups are due to peptization of the proteins, either caused by diagenesis, or a result of the gelatinization procedure. No other source of $-COOH/-COO^{-}$ groups, at the levels observed, is possible. The simultaneous

TABLE 2. Interpretation of major infra-red (IR) absorption bands for polyvinyl acetate (PVA), polyvinyl alcohol (PV-OH), collagen/gelatin, and peptides *

| Absorbance (Wave number in $cm^{-1}$) | Assignment |
|---|---|
| PVA and PV-OH | |
| 3600 - 3400 | -OH (hydrogen bonded in PV-OH) |
| 2950, 1380, 1440 | C-H absorbance ($CH_3$ and $CH_2$) |
| 1740, 1240 | C=O of acetate (residual in PV-OH) |
| 1130, 1030 | C-O-C of ester (PVA) |
| 1100 | 2° -OH of PV-OH |
| 940, 800 | C-C stretch (at 850 $cm^{-1}$ in PV-OH) |
| Collagen/gelatin | |
| 3400 | -OH (hydrogen bonded), and N-H |
| 2950, 1450, 1400 | C-H absorbance ($CH_3$ and $CH_2$) |
| 1650, 1550, 1240 | Amide I, II, and III, respectively |
| 1090, 1030 | 2° and 1° -OH, respectively |
| Peptides | |
| 1725, 1220 | C=O of -COOH (carboxylic acid) |
| 1650 | Amide I |
| 1480 region | C-H absorbance |
| 1400 | C=O of $-COO^-NH4^+$ (carboxylic acid salt) |

*From Haslem, Willis & Squirrel (1972); Bradbury *et al.* (1958)

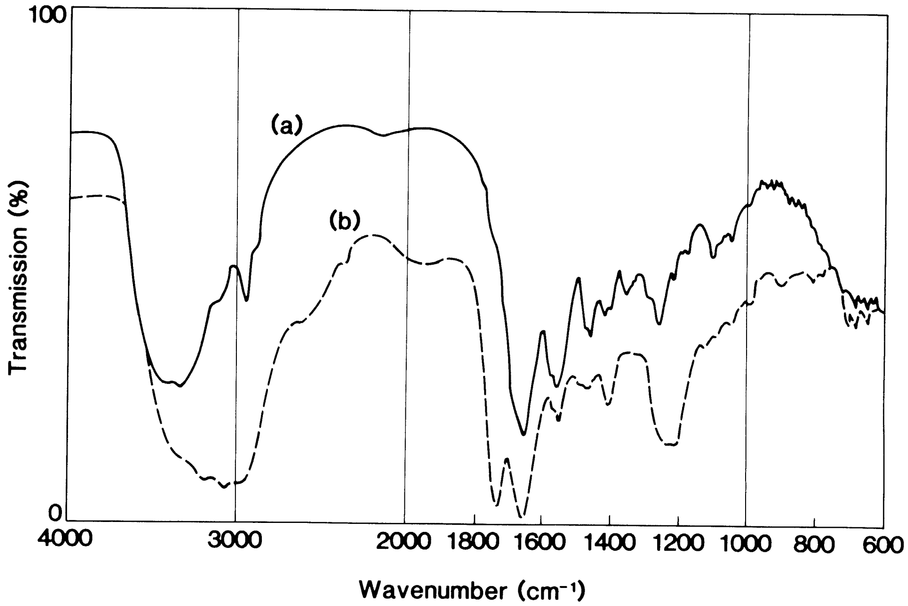

Fig. 2. Infra-red spectra of modern bovine collagen: (a) before partial hydrolysis by 0.1 M HCl (100°C, 16 h); (b) after partial hydrolysis by 0.1 M HCl (100°C, 16 h)

TABLE 3. Summary chart of predominant functional groups (as detected by IR spectroscopy) present in fractions extracted from conserved bones

| | Functional Group | | | | | | |
|---|---|---|---|---|---|---|---|
| | Consolidant | | | Protein | | | |
| | | | | Amide | | Peptide | |
| Context/ fraction | Acetate C=O | 2° -OH (PV-OH) | Ester C-O-C | I | II | COOH | $COO^-$ |
| [F7]c* | +** | + | + | + | + | −† | − |
| [F110]c | + | + | + | + | + | − | − |
| [F7]g | − | − | − | + | + | − | − |
| [F110]g | w‡ | + | + | + | + | − | − |
| [17F232]g | − | − | − | + | w | + | − |
| [F251]g | − | − | − | + | w | + | − |
| [F7]i | − | − | − | + | w | − | + |
| [F110]i | − | − | − | + | w | − | + |
| [17F232]i | − | − | w? | + | w | − | + |
| [F251]i | − | − | w? | + | w | − | + |

*c = crude collagen; g = crude gelatin; i = ion-exchanged gelatin

**+ Strong absorbance attributable to group present in spectra

†− No absorbance attributable to group is observed

‡w Weak absorbance, may be due to presence of specified group

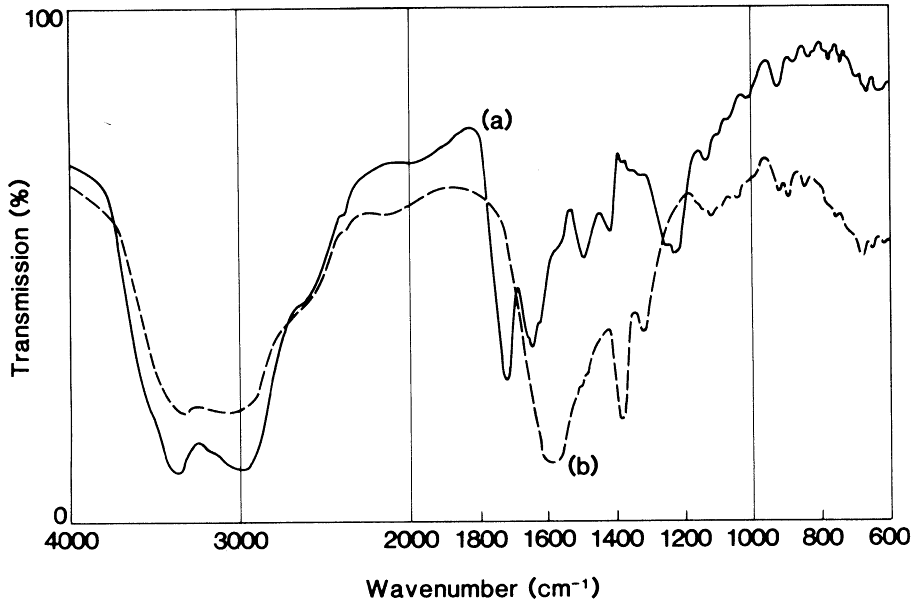

Fig. 3. Infra-red spectra showing peptized gelatin extracts from Burial 7 [17 F232]; (a) $H^+$ form, (b) $NH_4^+$ form after ion exchange on BioRad AGMP-50 resin

TABLE 4. AMS Dates on Human and Animal Bone From Cuello, Belize

| Context and fraction | OxA no. | $^{14}C$ date (BP) | $\delta^{13}C$ (‰) | Calibrated ranges[*] 1 sigma | 2 sigma |
|---|---|---|---|---|---|
| Human | | | | | |
| [F7]c[**] | p[†] 1653 | 2460 ± 70 | -11.0[‡] | 760–410 B.C. | 780–400 B.C. |
| 10 [F7]g | p 1654 | 2520 ± 70 | -11.0[‡] | 800–530 B.C. | 805–410 B.C. |
| [F7]i | p 1655 | 2530 ± 80 | -11.0[‡] | 810–410 B.C. | 810–410 B.C. |
| [F110]c | p 1648 | 3750 ± 70 | -11.0[‡] | 2300–2040 B.C. | 2460–1980 B.C. |
| [F110]g | p 1649 | 3000 ± 60 | -11.0[‡] | 1380–1135 B.C. | 1410–1060 B.C. |
| 62 [F110]a | p 2103 | 2840 ± 100 | -10.4 | 1205–900 B.C. | 1305–815 B.C. |
| [F110]r | p 2112 | 4540 ± 100 | -31.9 | 3375–3045 B.C. | 3600–2925 B.C. |
| [F110]a | - 2166 | 2830 ± 70 | -12.9 | 1120–905 B.C. | 1255–835 B.C. |
| 123 [F251]a | p 2016 | 2390 ± 70 | -11.0[‡] | 760–395 B.C. | 770–385 B.C. |
| 7 [17F232]a | p 2017 | 2560 ± 70 | -11.0[‡] | 810–540 B.C. | 840–410 B.C. |
| Animal | | | | | |
| [Q114]a | - 1811 | 2700 ± 90 | -20.1 | 985–800 B.C. | 1125–550 B.C. |
| [Q146]a | - 1810 | 2470 ± 80 | -15.9 | 765–415 B.C. | 785–405 B.C. |
| [Q44]a | - 2019 | 1650 ± 70 | -15.6 | A.D. 255–525 | A.D. 235–555 |
| [Q23]a | - 2018 | 1230 ± 80 | -13.3 | A.D. 690–880 | A.D. 660–965 |
| [Q109]a | - 1809 | 910 ± 120 | -20.0[‡] | A.D. 1015–1235 | A.D. 890–1285 |
| [Q74]a | - 1808 | 880 ± 110 | -19.9 | A.D. 1035–1235 | A.D. 900–1290 |

[*] Dendrochronological calibration based on high-precision curves of Stuiver & Pearson (1986); Pearson & Stuiver (1986); Pearson *et al.* (1986); and the calibration computer program of van der Plicht & Mook (1989).

[**] c = crude collagen; g = crude gelatin; i = ion-exchanged gelatin; a = amino acids from ion-exchanged gelatin; r = residue from gelatinization stage

[†] p = bone with PVA/PV-OH preservative; – = bone without PVA/PV-OH preservative

[‡] assumed (not measured) $\delta^{13}C$ values. The humans are assumed to have been eating maize, the −11‰ value being an approximate estimate based on the two measured bones which do indicate maize was an important component of the diet. The −20‰ value is based on the $\delta^{13}C$ measured for Q109, the other Postclassic animal bone, but since the species identity of the two bones is unknown, there is a margin of error.

reduction in the amide II absorbance, which is due partly to the presence of C-N bonds, supports the peptization theory. As these changes are not normally seen with better preserved samples, it would appear that the effect is due largely to the action of the tropical environment. Absorption in the region of acetate, alcohol and ester groups is weak for these samples, and similar in magnitude to that observed in the spectra of pure samples.

From the IR spectra, it appears that gelatinization and filtration alone may not remove adequately consolidants from bone extracts, but that ion exchange of the gelatin fraction does. However, the detection limits for contaminants using IR spectroscopy are such that observing contamination at the level of a few percent is not always possible, especially when diagenetic changes to the bone protein complicate the spectra. For this reason, hydrolysis of the proteins/peptides to free amino acids is usually carried out, and these are purified by ion-exchange chromatography.

## SIGNIFICANCE OF $^{14}C$ MEASUREMENTS

The dates obtained on the "control" samples, Q146 and Q114, are as expected, on stratigraphic and ceramic-typological grounds, and can be used as criteria by which the dates obtained on the conserved samples can be judged. From these dates, it appears that removal of environmental contaminants has been achieved by the pretreatment. Acceptable $^{14}C$ ages have also been obtained on the purified amino-acid fractions of the consolidated samples. When the dates obtained on the intermediate fractions from Burials 10 and 62 are studied, we can see that, where contamination of the sample by consolidant was high (*cf.* Burial 62, Fig. 4), a steady improvement in dating is obtained as the degree of purification increases, *i.e.*, the dates become younger, although the difference in age between the two gelatin fractions is not significant.

With Burial 10, the uniformity of the $^{14}C$ ages obtained on the three fractions points to less severe contamination, although consolidant was visible on the IR spectrum of the crude collagen fraction. In this case, gelatinization and filtration was sufficient to reduce the levels of PVA and PV-OH to below the IR detection limits.

Polymers such as PVA and PV-OH are normally manufactured from petrochemical precursors, and should contain no $^{14}C$ atoms. It would have been better to date the preservatives directly, but they were unavailable at the time of this study. When the residue remaining after the extraction of gelatin from Burial 62 was isolated and dated, a $^{14}C$ "age" of 4540 ± 100 B.P. was obtained, indicating that the residue probably contained "young" carbon from humic materials and insoluble collagen, as well as consolidant. The IR spectrum of the residue (Fig. 5B) showed that the strongest absorbance was in the C-O-C (from ester and ether groups) and O-H regions. Although this could be attributed to consolidant, the lack of definition in the spectrum indicates that environmental contaminants were also present.

No intermediate fractions were dated from Burials 123 and 7, but IR spectra on ion-exchanged gelatin showed that PVA and PV-OH were absent. The $^{14}C$ dates should, therefore, reflect the true age of the samples.

*Non-Burial Post-Preclassic Bone.* These samples had not been consolidated during excavation, nor had they been conserved subsequently. They were expected to pose problems caused by low levels of collagen and relatively high levels of soil-derived contaminants. In practice, 3 out of the 4 samples were relatively high in collagen, but Sample Q109, while having virtually no collagenous protein that could be extracted as gelatin, had an apparent "collagen" yield of 165 mg $g^{-1}$. With the other samples, between 70% and 25% of the crude collagen fraction was extractable as gelatin.

In such cases, the "collagen" fraction is a mixture of true collagen, diagenetically altered collagen (often not extractable as gelatin) and soil-derived material such as humic acids, rootlets and clay. Hydrolysis of this will release amino acids and sugars from all available sources, and these are likely to be "young," especially in tropical environments where turnover of unprotected organic matter is rapid. The amino-acid part of any aminosugar formed during hydrolysis need not derive from contamination; it is sufficient that the sugar part does, however. Purification of the hydrolyzate with decolorizing resins and ion exchange will remove non-amino contaminants only, leaving some "young" material in the final dating sample. This probably explains why the early AMS dates on amino acids from "collagen" were too young, even when the consolidant contaminants were "old."

The extraction of gelatin eliminates much of the environmental contaminants, although fulvic materials and, possibly, oligo- and polysaccharides associated with humic acids, can be co-extracted with the gelatin. These are removed by ion exchange of the proteins/peptides. The most important result, from the view of pretreatment in this section, is the date obtained on Q109, because this sample had only about 0.25% of its original collagen remaining as extractable gelatin. Previously, our laboratory methods were unsuitable for bones where less than about 5% of the original collagen remained. However, the accuracy of the date is supported by the agreement with that measured on

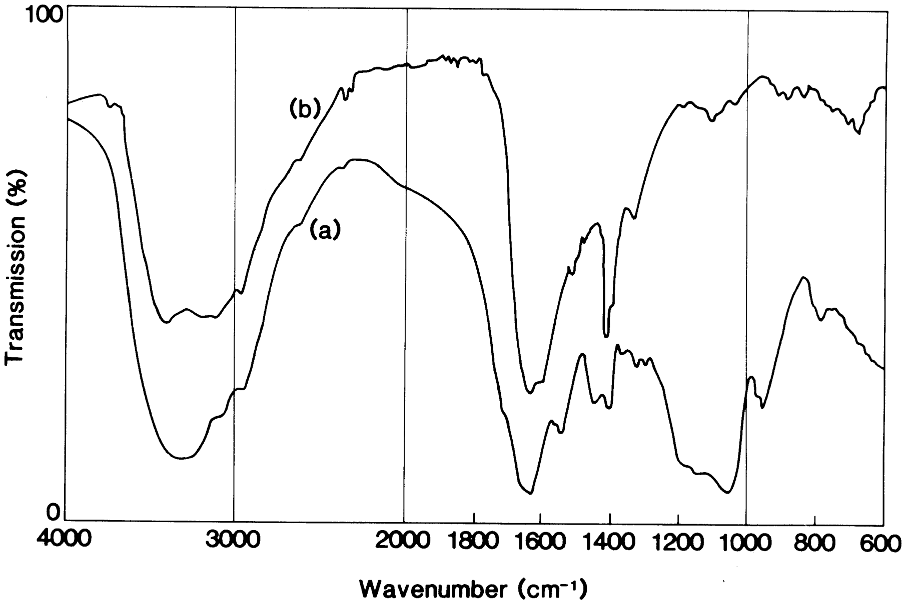

Fig. 4. Infra-red spectra of (a) crude gelatin, and (b) ion-exchanged gelatin fractions extracted from Burial 62 [F110]

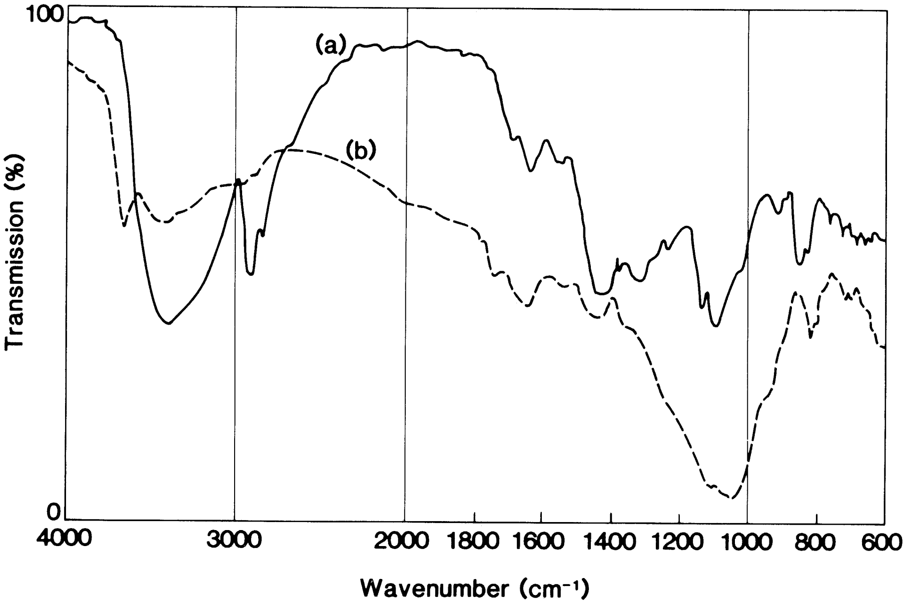

Fig. 5. Infra-red spectra showing (a) PV-OH, 14,000 mw (BDH Ltd.), and (b) residue remaining after extraction of crude gelatin from the "collagen" fraction of Burial 62 [F110]

the associated sample, Q74, and shows that our present pretreatment procedures can deal with very low levels of surviving collagen.

It is important to note that the methods and approaches adopted here correspond more or less to our 'routine' pretreatment methods for bone, which this project has, to a small extent, helped to validate. The circumstances in which we believe them to be valid very roughly apply to Holocene bone containing small but significant quantities of collagenous protein (at least 1%, *i.e.*, 2 mg $g^{-1}$, surviving extractable collagen), and subject to massive non-proteinaceous contamination. The general problem of radiocarbon dating bone, particularly in more extreme circumstances (*i.e.*, both older, and very much more reduced in collagen content, often to the point where only non-collagenous material remains) is the subject of much active research. See, *eg*, Stafford *et al.* (1991), van Klinken & Mook (1990), Ajie *et al.* (1990), Hedges & Law (1989) and references therein. However, we believe that the work reported here demonstrates the value of selective pretreatment aimed at isolating a truly representative protein/peptide fraction from degraded bone before any quantitative measurements (*e.g.*, $^{14}$C, $\delta^{13}$C, amino-acid content) are attempted.

## CONCLUSIONS

The ability of the AMS technique to handle milligram-sized samples allows separate fractions to be dated, so that the effect of the purification process can be monitored. Comparison of dates obtained on intermediate fractions with their IR spectra illustrates how IR spectroscopy can be used to assess the progress of the purification procedures. Using this technique, contamination in the dating sample can be detected, even when the $^{14}$C age of the net contamination does not differ greatly from that of the sample. This makes the evaluation of purification procedures less reliant on the actual $^{14}$C measurement, and applicable to a wider range of samples.

Although supported by two Preclassic non-human bone dates, Q114 and Q146, the four $^{14}$C dated burials from Cuello (7, 10, 62, 123), should be considered with some caution. However, we believe that we have come some way to resolving the controversy over the "long" and "short" chronologies for Cuello. We have obtained a set of direct dates that suggest an occupation beginning in the late second millennium cal. B.C., and that support the new ceramic chronology advanced by Andrews & Hammond (1990). Although this time span is over a millennium shorter than that initially proposed for Cuello, it is several centuries longer than the disturbingly recent dates for the Swasey phase indicated by the "short" chronology. If our direct dating of human burials is supported by further research, the chronology would place the Lopez Mamom phase at *ca.* 650–400 cal. B.C., the preceding Bladen phase at *ca.* 900–650 cal. B.C., and the Swasey phase at *ca.* 1200–900 cal. B.C. (Fig. 1). The dates for Mamom sphere ceramic complexes elsewhere, and for the Xe complex, which is the equivalent of Bladen further southwest in the Maya lowlands, would be in close agreement with the revised Cuello chronology.

The stratigraphically late animal bone samples, especially Q74 and Q109, indicate that architectural additions to the temple-pyramid Structure 35 were still being made, and the residential group just to the north was still occupied in the Postclassic period. The 12th century A.D. date suggested accords with other archaeological evidence from Cuello, which until now had been interpreted as only a pilgrimage visitation of the site from a nearby community (Hammond, Housley & Law 1991).

Overall, the application of AMS dating to microscopic samples of organic material from badly denatured human and animal bone has proved remarkably successful in resolving vexing matters of ancient Maya chronology.

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# A RADIOCARBON CHRONOLOGY FOR HUMAN-INDUCED ENVIRONMENTAL CHANGE ON MANGAIA, SOUTHERN COOK ISLANDS, POLYNESIA

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**ABSTRACT.** A suite of 23 $^{14}$C age determinations, from a well-stratified rockshelter and from 3 pollen cores on Mangaia Island is reported. The rockshelter has yielded significant evidence for avifaunal extinctions during the period cal. A.D. 1000–1600. The Lake Tiriara pollen cores span a period from *ca.* 6500 cal. B.P. to the present, and palynological analysis of the TIR 1 core indicates major anthropogenic disturbance on the island's vegetation after *ca.* 1600 cal. B.P. These sites, and the radiocarbon ages associated with them, provide the first chronologically secure evidence for human impacts on the island ecosystems of the southern Cook Islands.

## INTRODUCTION

For years, anthropologists and archaeologists tacitly assumed that prehistoric Polynesians had little impact on their island ecosystems; island environments were regarded as essentially static backdrops for colonizing human cultures. Similar assumptions were made by biogeographers, who viewed most change as having occurred after the arrival of Europeans. Thus, such classic studies of island biogeography as MacArthur and Wilson (1967) accepted historic-period data on animal and plant species frequencies and distributions as representing 'natural' situations.

Recently, a spate of archaeological, paleontological, palynological and geoarchaeological investigations in Polynesia has demonstrated that prehistoric Polynesians, in fact, had a significant impact on their insular ecosystems (*e.g.*, Kirch 1982, 1983; Steadman 1989; Olson & James 1984; Pregill & Dye 1989; Christensen & Kirch 1986; Flenley & King 1984; McGlone 1983; Kirch & Yen 1982; Hughes *et al.* 1982). It is now evident that Polynesians often precipitated major changes in their island environments, including deforestation and other forms of habitat disturbance and destruction, extinction and/or extirpation of endemic biota, introduction of competitive species of weeds and pests, and soil erosion with increased rates of alluvial sedimentation in valley bottoms. From the human perspective, not all of these impacts were necessarily deleterious; alluviation sometimes enhanced island agricultural regimes (Spriggs 1986). Nonetheless, from a biotic perspective, the impacts of Polynesians on endemic and vulnerable island biotas (Fosberg 1963) were frequently devastating. Some of the most dramatic evidence has come from archaeological assemblages of bird bones, indicating massive extinction of native land birds in such island groups as Hawaii, the Marquesas, Society and Cook Islands (Steadman 1989).

In order to learn more about how the prehistoric Polynesians modified island ecosystems, we initiated an interdisciplinary study of human-induced environmental change on Mangaia Island, in the Southern Cook Islands (Fig. 1), with a first season of fieldwork in 1989. Our approach applies the methods of archaeology (PVK), avian paleontology (DWS), and palynology (JF) in a coordinated field and laboratory study. Mangaia was chosen as the field site because: 1) preliminary work by DWS had revealed important bone assemblages of extinct land birds with cultural associations (Steadman 1985, 1987); 2) several small lakes on the island seemed suitable for taking sediment cores; 3) ethnohistoric data suggested severe deforestation and cultural stress resulting from overpopulation and competition for limited agricultural lands (Gill 1894; Buck 1934). Prior

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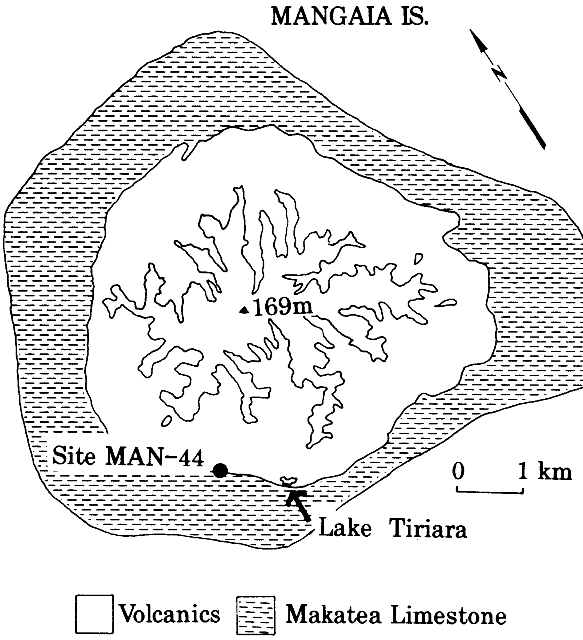

Fig. 1. Map of Mangaia Island, showing the locations of Tangatatau (Site MAN-44) and Lake Tiriara

to our study, the island had been only cursorily investigated from an archaeological perspective (Bellwood 1978).

Mangaia (21°55′S, 157°55′W) is a small island (52 km$^2$) at the southeast end of the Cook Islands. Geologically, Mangaia is part of the Cook-Austral Island chain (Turner & Jarrard 1982). A central core of highly weathered volcanics (*ca.* 18 My B.P.) with radial stream drainage is surrounded by a ring of emerged reef limestones dating to at least 110 ka B.P. (Marshall 1927; Stoddart, Spencer & Scoffin 1985). The central volcanic cone is heavily eroded, and supports only an open, pyrophytic association of scrub *Pandanus, Casuarina, Dicranopteris (Gleichenia)* fern, and grasses. The limestone terrain (called *makatea*) supports a depauperate rainforest dominated by the trees, *Hernandia moerenhoutiana, Guettarda speciosa, Elaeocarpus tonganus, Pandanus tectorius* and *Ficus prolixa* (Merlin 1991). At European contact and into the present century, the Polynesian occupants have practiced intensive pondfield irrigation of taro (*Colocasia esculenta*) on the hydromorphic alluvial soils of the radial stream valley bottoms.

Our 1989 fieldwork focused on the Veitatei District, which is both a natural geomorphic unit (a radial stream drainage system) and a traditional Polynesian chiefdom territory. Following initial reconnaissance, during which a number of late prehistoric habitation and temple sites (*marae*) were recorded, we decided to concentrate our efforts on two projects. The first was intensive excavation of a large rockshelter site (Tangatatau, Site MAN-44), which promised to yield a well-stratified sequence of cultural deposits. The second was coring of Lake Tiriara in order to obtain a continuous sediment sequence for pollen analysis. Figure 1 shows both the Tangatatau and the Lake Tiriara sites.

We report here a suite of 23 $^{14}$C age determinations from Mangaia; 15 of these are from our excavations at the stratified Tangatatau rockshelter site, and 8 are from sediment cores in Lake

Tiriara. Following a brief summary of the sites and a review of the dates, we discuss the significance of these $^{14}$C determinations, paying special attention to the chronology of human occupation of Mangaia and the impact of such occupation on the island ecosystem.

## THE TANGATATAU SITE (MAN-44)

Tangatatau is the local Mangaian name for a large rockshelter formed by an overhanging block of the inner cliff of the *makatea* limestone in Veitatei District (Fig. 1). The rockshelter lies at the base of a long, gentle volcanic slope rising northward toward the interior of the island. Lake Tiriara, where our pollen cores were obtained, lies approximately 0.9 km southeast of the rockshelter.

Our reconnaissance survey of Veitatei indicated that Tangatatau (designated site MAN-44 in our island-wide catalog of archaeological sites) was the most likely site to yield a well-stratified cultural sequence, due to the extent of habitable surface area under the drip line (225 m$^2$), and because the surface contours suggested considerable depth of deposit. Therefore, we focused our excavations on this site for three weeks in July–August 1989. A more complete report on these excavations is forthcoming (Kirch & Steadman, Archaeological excavations at Tangatatau Rockshelter, Mangaia Island, ms. in preparation); here we mention only a few points critical to understanding the context of the $^{14}$C determinations.

Our primary excavation was a 1 × 5 m trench (grid units C30–G30) bisecting the main rockshelter floor from the rear shelter wall to a point some 3–4 m from the drip line. A 1 m$^2$ test unit (grid unit F10) also was excavated in a second open floor area 20 m west of the main trench. Radiocarbon age determinations were obtained from both the main trench and the F10 test unit, revealing comparable age-depth sequences for both sectors of the site (see below).

The stratigraphy of the main trench was extremely complex, with 36 discrete depositional units and features identified in the west face, which will be described and illustrated in detail in Kirch and Steadman (ms. in preparation). The section has a total depth of about 1.6 m. For purposes of correlation and tabulation of excavated materials, we have designated 10 'analytic zones' for the main trench, labeled A to J (from top to bottom of the section), and determined independently of the radiocarbon and faunal data. In brief, the base of the section (Zone J) consists of a reddish-yellow (5 YR 7/6-7) fine, silty-clay derived from decomposed limestone, containing numerous small terrestrial gastropod shells, and representing the prehuman occupation phase. Overlying this is a set of relatively massive layers and beds (Zones I–G) of brown to dark brown (7.5 YR 5/2 to 7.5 YR 4/2) ashy midden, with large charcoal pieces scattered throughout. This early phase appears to represent a period of continuous human occupation of the shelter as a primary residential site. At *ca.* 0.6 m below surface, there is a marked change in the sedimentary regime, with the initiation of a series of discrete lenses of yellowish-red (5 YR 4–5/6) sticky clay (Zones F–B), intercalated with thin shell-midden beds, finely bedded ash deposits and various oven and hearth deposits. This upper stratigraphic regime evidently resulted from periodic fluvial deposition of volcanic clays onto the shelter floor, alternating with phases of occupation and shell-midden dumping. The uppermost 10 cm of the section (Zone A) consists of a horizontally continuous deposit of dark reddish-brown (5 YR 3/2) ashy silt, rich in charcoal and undecomposed organic materials (leaves, *Pandanus* fruit and wood fragments) mixed with a few historic-period artifacts.

The stratigraphic sequence in grid unit F10 was apparently less complex than in the main trench, although the presence of a large earth oven feature made interpretation of the section more tenuous.

The occupation deposits yielded a rich array of artifacts as well as both vertebrate and invertebrate faunal materials. The main artifact classes include fishing gear (especially one-piece fishhooks), coral and urchin-spine abrading tools, stone adzes, shell pendants, bone tattooing chisels, a coral gaming stone and large numbers of chipped basalt and chert flakes and cores. The one-piece fishhooks display a significant sequence of change, with hooks of exotic pearl shell (*Pinctada* sp.) in the lower occupation component, followed by hooks manufactured from the locally occurring *Turbo setosus* in the upper component. The basalt adzes also reveal a sequence of typological change, from untanged adzes in the lower component to typical, late-prehistoric Cook Islands tanged adzes in the upper component.

The invertebrate faunal materials are dominated by mollusks, largely species that occur along the narrow, exposed fringing reef that surrounds Mangaia Island. These include both gastropods and bivalves. Our analysis of these mollusks is still in process, but it is evident that there is statistically significant size reduction from early to late strata in at least the *Turbo* shells, probably due to intense human predation and exploitation of this species for food. Also present in the invertebrate faunal assemblage are crustaceans and echinoderms.

We recovered a total of 11,179 vertebrate faunal specimens from the 6 $m^2$ excavated. Of these, the majority (90%) are bones of small reef fish such as scarids, labrids and acanthurids. Of particular note, however, are 212 bones of native species of birds. These include both seabirds (in the genera *Puffinus, Pterodroma, Nesofregetta, Phaethon, Fregata, Anous, Procelsterna* and *Gygis*) and land birds (in the genera *Anas, Pluvialis, Gallirallus, Porzana, Gallicolumba, Ptilinopus, Ducula, Vini, Halcyon* and *Acrocephalus*). The land birds are of particular interest, as many of the species represented in the rockshelter midden are extinct and/or extirpated on Mangaia (Steadman & Kirch 1990). Except for a single bone of *Ptilinopus*, the extinct/extirpated species are confined to the lower occupation component of the site (Analytic Zones J–G). Also well represented in these lower stratigraphic zones are bones of the indigenous fruit bat, *Pteropus tonganus*, today a threatened species represented by < 200 individuals. The vertebrate faunal assemblage also documents the introduction to the island in prehistory of the Polynesian rat (*Rattus exulans*) and of the domestic pig (*Sus scrofa*); the bones of these latter species are especially prevalent in the upper, later-prehistoric occupation deposits.

## THE TANGATATAU RADIOCARBON SEQUENCE

The 15 $^{14}$C samples from Tangatatau were selected at the close of the field season, out of a total of 22 potentially datable charcoal samples. Priority was given to samples collected from discrete features (*e.g.*, lenses, earth ovens, hearths) in well-controlled stratigraphic contexts. Samples were also selected to provide relatively complete vertical representation of the stratigraphic column. Four samples are from unit F10, and the other 11 samples from the C30–G30 main trench. In virtually all cases, the dated charcoal was a mixture of carbonized wood, candlenut (*Aleurites moluccana*) endocarp fragments and *Pandanus tectorius* drupes. All samples were collected directly into foil and then bagged in heavy polyethylene bags.

All samples were processed and analyzed by Beta Analytic, Inc. The charcoal was pretreated by first examining for rootlets, followed by a hot acid wash to eliminate carbonates. Samples were then repeatedly rinsed to neutrality and subsequently given a hot alkali soaking to remove humic acids. After rinsing to neutrality, another acid wash followed, with subsequent rinsing to neutrality. Benzene syntheses and counting proceeded normally (M. Tamers, personal communication, 21 Sept. 1989). Six of the samples proved to be quite small after pretreatment (Beta-32816, -32817, -32824, -32835, -32826 and -32829), and were thus accorded extended counting times (4 × the normal counting period), in order to reduce statistical error. The $^{13}$C/$^{12}$C ratios were measured for all samples to establish $^{13}$C adjusted, “conventional $^{14}$C ages” (Stuiver & Polach 1977). These conventional age determinations, $^{13}$C/$^{12}$C values, and details of all samples are presented at the end of this paper.

Calibration of ages for secular effects follow Stuiver and Becker (1986) for samples grown in terrestrial environments. Calibrations and probability estimates were made using Revision 2.0 of the "Calib" FORTRAN microcomputer program (Stuiver & Reimer 1986).

The 11 $^{14}$C age determinations from the main trench excavations are plotted in Figure 2 as calibrated A.D. ranges at 1 $\sigma$, according to stratigraphic position (analytic zones); the 4 age determinations from the F10 grid unit are similarly plotted in Figure 3. With three exceptions, these age determinations fall into a consistent stratigraphic order. The exceptions are samples Beta-32817, -32821 and -32825. Of these, Beta-32817 and -32821, from the main trench actually overlap stratigraphically related samples at 2 $\sigma$; as can be seen in the diagram; however, their calibrated ranges are extremely long, extending to A.D. 1955. Thus, they can be discounted as being of little use in determining an age-depth curve for the site. The third apparently aberrant sample, Beta-32825, comes from the stratigraphically complex grid unit F30, in which a number of prehistoric pits had been excavated into the deeper, ashy midden deposits in the basal portion of the section. It is probable that the charcoal dated in this sample actually derived from the earliest occupation phase (analytic zone I), and had been displaced by a pit dug during deposition of analytic zone G.

In general, the $^{14}$C ages from Tangatatau fall into a consistent age-depth sequence beginning about cal. A.D. 1000–1100 and extending up until about cal. A.D. 1500–1600. Thus, it appears that the site was occupied more or less continuously over a period of some 4–6 centuries. This period was one

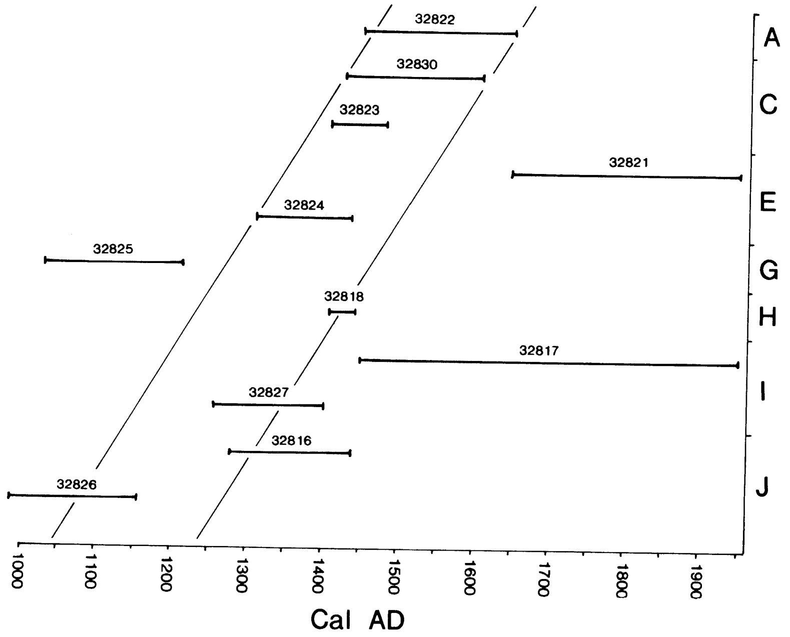

Fig. 2. Radiocarbon age determinations from the main excavation trench in Tangatatau rockshelter, plotted as cal. A.D. ages at 1 $\sigma$, arrayed according to analytic zones (*i.e.*, in stratigraphic position)

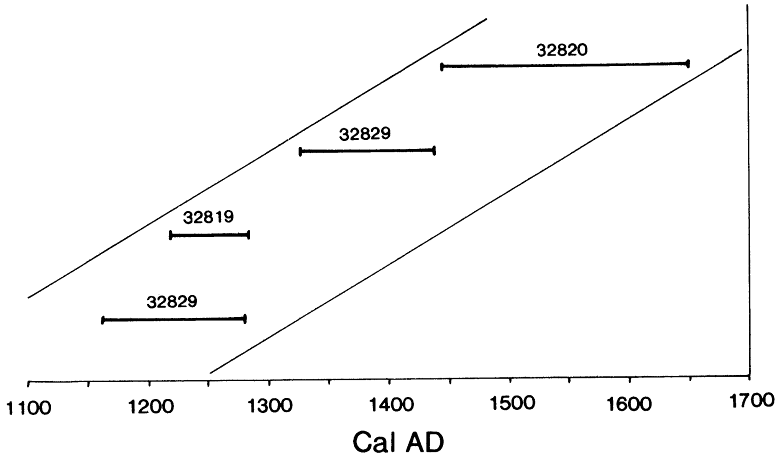

Fig. 3. Radiocarbon age determinations from grid unit F10 in Tangatatau rockshelter, plotted as cal. A.D. ages at 1 σ, arrayed according to stratigraphic position

of major changes in Mangaian culture and ecology, as witnessed by changes in the artifactual and faunal assemblages (Steadman & Kirch 1990; Kirch & Steadman, ms. in preparation). Further, the two oldest $^{14}C$ ages from Tatangatau provide the earliest artifactual evidence of human occupation on Mangaia.

### THE LAKE TIRIARA RADIOCARBON SEQUENCE

In order to obtain sediment samples for palynological analysis and determination of changes in the island's vegetational history, three cores were taken in Lake Tiriara (Fig. 1). The sedimentology of the cores was studied by Dawson (1990). Core TIR 1 was taken in the approximate center of the lake (water depth 2.1 m), from a floating platform constructed of inner tubes and plywood. TIR 1 had a total length of 14.89 m, and consisted largely of organic lacustrine sediment (gyttja) with some clay banding, particularly in the upper portion of the core. Core TIR 2 was taken at the edge of the swamp bordering the lake (*ca.* 49 m from TIR 1), and had a total depth of 11.55 m. The upper 4 m of this core consist primarily of clay, grading into gyttja with clay and charcoal banding in the deeper portions of the core. Core TIR 3 was taken farther away from the lake into the swampy valley bottom; the total depth of TIR 3 was 12.47 m. As in TIR 2, the upper portion of this core consisted dominantly of clays, grading into peats and gyttja in the deeper portions.

Eight sediment samples from the Lake Tiriara cores were submitted for $^{14}C$ determination, 6 from TIR 1, and 1 each from TIR 2 and 3. The samples were pretreated by first picking for any rootlets; they were then dispersed in hot acid to eliminate carbonates, repeatedly rinsed to neutrality, dried and combusted in an enclosed system (M. Tamers, personal communication, 5 Oct. 1989). All benzene syntheses and countings proceeded normally. Conventional $^{14}C$ ages, $^{13}C/^{12}C$ values, and relevant sample information for these samples are presented at the end of this paper.

The Lake Tiriara pollen core sample ages are plotted in Figure 4 as 1 σ cal. B.P. age ranges, arrayed by depth below the surface of the deposit. All eight samples display a remarkably clear and consistent age-depth progression, and suggest that the lake and valley-bottom swamp system, of which it is a part, have had a fairly constant rate of infilling over the past 6500 years. The sedi-

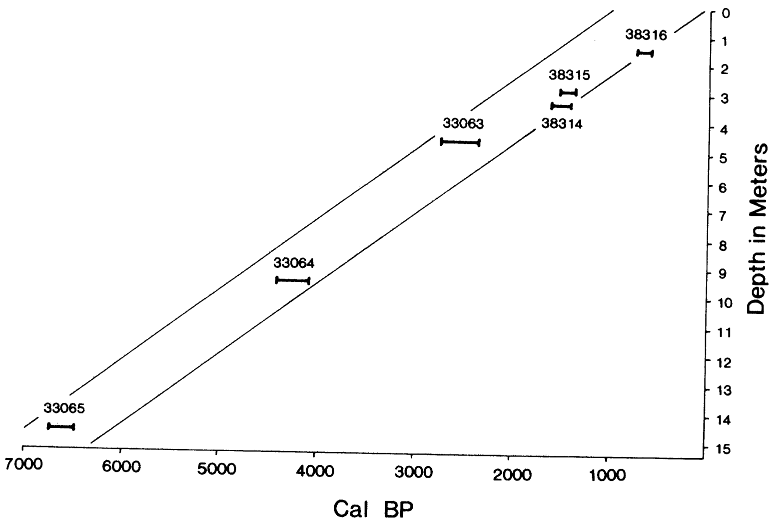

Fig. 4. Radiocarbon age determinations from the TIR-1 Lake Tiriara pollen core, plotted as cal. B.P. ages at 1 σ, according to depth in meters below the surface. Note that all six ages suggest a regular age-depth curve.

mentary change in the TIR-2 and -3 cores, from peat and gyttja to clays in the upper 4 m, apparently took place after about 2000 B.P.

Lamont (1990) has analyzed the pollen record of the TIR core, which provides a vegetation history for Mangaia spanning the past 6500 years. Details of this sequence, and its correlation with the island's archaeological sequence, will be discussed at greater length elsewhere. Briefly, the pollen record can be divided into three zones. Zone 3, at the base of the TIR 1 core, dates between about 6500 and 6000 cal. B.P., and displays a relatively "high proportion of tree pollen," dominated by *Weinmannia* (Cunoniaceae) and *Meryta* (Araliaceae) (Lamont 1990: 30–31). There is some indication of disturbance towards the middle of Zone 3, possibly due to the effects of tropical cyclones. Zone 2 dates from about 6000 to 1600 cal. B.P. This zone is again marked by a relatively high proportion of tree pollen and low frequency of ferns. The effects of rising Holocene sea levels at about 3700 cal. B.P. are suggested by the appearance of Rhizophoraceae, and corroborate geomorphological indications of an approximately +1 m seastand at this time (Yonekura *et al.* 1988). The most dramatic change in the pollen record occurs in Zone 1, dated from about 1600 cal. B.P. to the present. This zone is "marked by a significant decrease in the tree pollen and the disappearance of primary taxa such as *Weinmannia*" (Lamont 1990: 34). There is also a dramatic increase in fern spore frequencies, such as *Dicranopteris (Gleichenia)*, and increases in secondary taxa. There appears to be little doubt that Zone 1 reflects the impacts of prehistoric Polynesian forest clearance on the central volcanic cone of Mangaia. This forest clearance resulted in substantial erosion and creation of the pyrophytic fern-*Pandanus* association that has dominated the volcanic interior in historic times.

The Zone 2/Zone 1 boundary is bracketed by $^{14}C$ determinations Beta-38314 and -38315. These suggest that the onset of Polynesian forest clearance began between about 1600 and 1400 cal. B.P. This is several hundred years earlier than the age of the basal cultural deposits in the Tangatatau rockshelter. We believe that the pollen record may be a better indicator of the probable age of initial human colonization of Mangaia, *i.e.*, early in the first millennium A.D.

## DISCUSSION AND IMPLICATIONS

The radiocarbon age determinations reported herein are the first to be reported from Mangaia in association with cultural materials, and provide both the first chronometric evidence for the span of human occupation of the island, and also critical information on the timing of major environmental changes. The radiocarbon series from Tangatatau rockshelter indicates that prehistoric Polynesians were well established on the island by ca. A.D. 1000–1100. These Polynesians had introduced the rat (*Rattus exulans*), chicken (*Gallus gallus*) and pig (*Sus scrofa*), and were exploiting a broad spectrum of indigenous and endemic birds, fruit bats, sea turtles, fishes and invertebrates for food. They manufactured one-piece fishhooks from imported pearl-oyster shell (*Pinctada* sp.), and also used a variety of other typical East Polynesian artifacts.

It is unlikely, however, that the basal levels of the Tangatatau site represent an initial colonization phase. The presence of large numbers of extinct bird bones in the early levels of Tangatatau might be taken as evidence that the site was occupied at the beginning of the island's prehistoric cultural sequence. However, these basal levels in Tangatatau may simply represent a phase of *local* impact on the Veitatei District fauna, some time after first colonization of the island by humans. This latter alternative is reinforced by the evidence of the Lake Tiriara pollen record, which shows accelerated erosion of the central volcanic core and significant decreases in tree pollen along with increases in fern spores, beginning about 1600 cal. B.P.

Polynesians clearly had a dramatic impact on the island's ecology during the past 1600 years. This is most evident in the extinction and extirpation of no less than nine species of landbirds (rails, pigeons, doves and parrots). However, human impact is also evident in the significant reductions in numbers of fruit bat (*Pteropus tonganus*), and in size reductions in mollusks gathered for food from the narrow fringing reef. Another kind of impact is suggested by the changes in the Lake Tiriara sedimentary regime, with a shift to dominantly clay sediments in the upper levels. This is correlated with forest clearance on the central volcanic cone (as a result of horticultural activities), thereby inducing erosion of the lateritic soils. In sum, the archaeological, geomorphological and palynological evidence obtained from Mangaia during our 1989 investigations document a sequence of pronounced anthropogenic impacts on this island ecosystem. It is our intention to explore this sequence of ecological change further, and to study its effects on the evolution of Mangaian culture and society, through continued field and laboratory investigations.

## ACKNOWLEDGMENTS

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## ARCHAEOLOGICAL SAMPLES

### Tangatatau Site series

**550 ± 120**

**Beta-32816.** Tangatatau $\delta^{13}C = -27.3‰$

Site MAN-44, Unit E30, W face. Charcoal from under roof-fall limestone boulder. Analytic zone J. (Field sample no. C-1) Extended counting time sample (0.29 g carbon). Cal. A.D. 1280 (1407) 1440 at 1 σ; cal. B.P. 670 (543) 510 at 1 σ.

**230 ± 160**

**Beta-32817.** Tangatatau $\delta^{13}C = -28.1‰$

Site MAN-44, Unit C30, Level 10. S half of unit. 1.2–1.3 cm below surface. Charcoal. Analytic zone I (correlation tentative). (Field sample no. C-2) Extended counting time sample (0.24 g carbon). Cal. A.D. 1450 (1656) 1955 at 1 σ; cal. B.P. 500 (294) 0 at 1 σ.

**490 ± 50**

**Beta-32818.** Tangatatau $\delta^{13}C = -26.6‰$

Site MAN-44, Unit F30, Level 10. From charcoal concentration in NW corner of unit, 1.36 cm below surface. Analytic zone H. (Field sample no. C-3) Cal. A.D. 1409 (1426) 1440 at 1 σ; cal. B.P. 541 (524) 510 at 1 σ.

**740 ± 80**

**Beta-32819.** Tangatatau $\delta^{13}C = -26.9‰$

Site MAN-44, Unit F10, Level 8. Feature 2, at 1.23 cm below datum. Single large piece of wood charcoal. (Field sample no. C-4) Cal. A.D. 1218 (1277) 1285 at 1 σ; cal. B.P. 732 (673) 665 at 1 σ.

**330 ± 80**

**Beta-32820.** Tangatatau $\delta^{13}C = -26.0‰$

Site MAN-44, Unit F10, Level 2. (Field sample no. C-5). Cal. A.D. 1446 (1521, 1590, 1623) 1650 at 1 σ; cal. B.P. 504 (429, 360, 327) 300 at 1 σ.

**200 ± 60**

**Beta-32821.** Tangatatau $\delta^{13}C = -26.8‰$

Site MAN-44, Unit G30, Level 4. Charcoal from earth oven. Analytic zone E. (Field sample no. C-6). Cal. A.D. 1647 (1665, 1784, 1788, 1949, 1952) 1955 at 1 σ; cal. B.P. 303 (285, 166, 162, 1, 0) 0 at 1 σ.

**330 ± 80**

**Beta-32822.** Tangatatau $\delta^{13}C = -26.7‰$

Site MAN-44, Unit E30, Level 2. Charcoal from approximately 66 cm below surface. Analytic zone A. (Field sample no. C-7) Cal. A.D. 1446 (1521, 1590, 1623) 1650 at 1 σ; cal. B.P. 504 (429, 360, 327) 300 at 1 σ.

**450 ± 70**
**Beta-32823.** Tangatatau $\delta 13 = -26.6$‰

Site MAN-44, Unit F30, Level 3. Analytic zone C. (Field sample no. C-8) Cal. A.D. 1414 (1437) 1480 at 1 σ; cal. B.P. 536 (513) 470 at 1 σ.

**540 ± 80**
**Beta-32824.** Tangatatau $\delta^{13}C = -29.5$‰

Site MAN-44, Unit D30, Level 6; 1.18 cm below datum. Analytic zone E. (Field sample no. C-9) Extended counting time sample (0.54 g carbon). Cal. A.D. 1311 (1410) 1435 at 1 σ; cal. B.P. 639 (540) 515 at 1 σ.

**900 ± 70**
**Beta-32825.** Tangatatau $\delta^{13}C = -27.0$‰

Site MAN-44, Unit F30, Level 9. Analytic zone G. (Field sample no. C-10). Extended counting time sample (0.81 g carbon). Cal. A.D. 1024 (1133, 1136, 1156) 1216 at 1 σ; cal. B.P. 926 (817, 814, 794) 734 at 1 σ.

**980 ± 70**
**Beta-32826.** Tangatatau $\delta^{13}C = -27.3$‰

Site MAN-44, Unit E30, Level 13. Charcoal from small lens at contact of levels 12–13; 1.54 cm below datum. Analytic zone J. (Field sample no. C-11) Extended counting time sample (0.61 g carbon). Cal. A.D. 988 (1023) 1155 at 1 σ; cal. B.P. 962 (927) 795 at 1 σ.

**700 ± 80**
**Beta-32827.** Tangatatau $\delta^{13}C = -27.9$‰

Site MAN-44, Unit C30, Level 11. Charcoal in pit fill. Analytic zone I. (Field sample no. C-12) Cal. A.D. 1259 (1280) 1387 at 1 σ; cal. B.P. 691 (670) 563 at 1 σ.

**790 ± 80**
**Beta-32828.** Tangatatau $\delta^{13}C = -27.7$‰

Site MAN-44, Unit F10, Level 8. Charcoal from Feature 2, 1.23 cm below datum. (Field sample no. C-13) Cal. A.D. 1162 (1257) 1280 at 1 σ; cal. B.P. 788 (693) 670 at 1 σ.

**520 ± 70**
**Beta-32829.** Tangatatau $\delta^{13}C = -27.2$‰

Site MAN-44, Unit F10, Level 3. Charcoal at base of level 3, at contact of midden deposit with reddish silty-clay subsoil. (Field sample no. C-14) Extended counting time sample (0.67 g carbon). Cal. A.D. 1327 (1415) 1438 at 1 σ; cal. B.P. 623 (535) 512 at 1 σ.

**420 ± 70**
**Beta-32830.** Tangatatau $\delta^{13}C = -26.4$‰

Site MAN-44, Unit F30, Level 3. Charcoal from thin lens, collected in situ, 0.69 cm below datum. Analytic zone C. (Field sample no. C-15) Cal. A.D. 1425 (1443) 1612 at 1 σ; cal. B.P. 525 (507) 338 at 1 σ.

## PALYNOLOGICAL SAMPLES

### Lake Tiriara series

**2450 ± 80**

**Beta-33063.** Lake Tiriara $\delta^{13}C = -27.2‰$

Sediment from core TIR 1, 4-61–4.71 m depth. Cal. BC 778 (752, 709, 530) 403 at 1 σ; cal. B.P. 2727 (2701, 2658, 2479) 2352 at 1 σ.

**3860 ± 90**

**Beta-33064.** Lake Tiriara $\delta^{13}C = -27.7‰$

Sediment from core TIR 1, 9.60–9.70 m depth. Cal. BC 2468 (2343) 2149 at 1 σ; cal. B.P. 4417 (4292) 4098 at 1 σ.

**5810 ± 100**

**Beta-33065.** Lake Tiriara $\delta^{13}C = -26.8‰$

Sediment from core TIR 1, 14.75–14.85 m depth. Cal. BC 4790 (4719) 4545 at 1 σ; cal. B.P. 6739 (6668) 6494 at 1 σ.

**4770 ± 80**

**Beta-33066.** Lake Tiriara $\delta^{13}C = -25.1‰$

Sediment from core TIR 2, 12.65–12.75 m depth. Cal. BC 3646 (3619, 3576, 3531) 3382 at 1 σ; cal. B.P. 5595 (5568, 5525, 5480) 5331 at 1 σ.

**3820 ± 80**

**Beta-33067.** Lake Tiriara $\delta^{13}C = -26.0‰$

Sediment from core TIR 3, 9.85–9.95 m depth. Cal. BC 2458 (2288) 2142 at 1 σ; cal. B.P. 4407 (4237) 4091 at 1 σ.

**1640 ± 50**

**Beta-38314.** Lake Tiriara $\delta^{13}C = -25.0‰$

Sediment from core TIR 1, 3.3–3.4 m depth. This sample lies just below the Zone 2/Zone 1 boundary of the pollen sequence. Cal. A.D. 343 (411) 527 at 1 σ; cal. B.P. 1607 (1539) 1423 at 1 σ.

**1550 ± 60**

**Beta-38315.** Lake Tiriara $\delta^{13}C = -25.0‰$

Sediment from core TIR 1, 2.8–2.9 m depth. This sample lies just above the Zone 1/Zone 2 boundary of the pollen sequence. Cal. A.D. 426 (482, 488, 534) 572 at 1 σ; cal. B.P. 1524 (1468, 1462, 1416) 1378 at 1 σ.

**1350 ± 110**

**Beta-38316.** Lake Tiriara $\delta^{13}C = -25.0‰$

Sediment from core TIR 1, 1.5–1.6 m depth. Cal. A.D. 600 (661) 770 at 1 σ; cal. B.P. 1350 (1289) 1180 at 1 σ.

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# PHYSICAL RESEARCH LABORATORY RADIOCARBON DATE LIST VI

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We present here dates for archaeological and geological samples. The dates are based on $\tau_{1/2}$ = 5568 years, using 1950 as the base year. The modern standard was 95% of activity of NBS oxalic acid.

Samples were pretreated, prepared by methane synthesis and counted in a proportional counter. The detailed procedure has been described earlier (Agrawal, Gupta & Kusumgar 1971). We reported minor changes in previous date lists. Quoted errors are based on counting statistics alone. For samples younger than 10,000 years, the error is 1 standard deviation, and for older samples, 2 standard deviations. The dates are not corrected for $^{13}$C fractionation. Samples have been arranged alphabetically according to the name of the site.

## ARCHAEOLOGICAL SAMPLES

### *India*

**PRL-937. Adiyaman Kottai, BRW deposit** **1720 ± 150**

Charcoal from Adiyaman Kottai (12°05′N, 78°10′E), Dharmapuri dist., Tr. AMK-2, Layer Pit 24, 4.37 m depth; subm. by K. V. Raman, Madras Univ.; Sample 1.

*Comment*: dates Black-and-Red Ware (BRW) levels of site.

**PRL-930. Aguncha Old Mine** **2860 ± 100**

Wood from Aguncha (25°45′N, 74°46′E), Ajmer dist., 20 m depth; subm. by D. K. Chakrabarti, Dept. History, Delhi Univ.; Sample 4.

*Comment:* dates Aguncha mine.

### Alagankulam series, Tamil Nadu

Alagankulam, Ramanthapuram dist., Tamil Nadu State; subm. by Dr. R. Nagaswamy, State Dept. Archaeol., Mandavalli, Madras.

**PRL-1296. BRW levels** **2090 ± 100**

Charcoal, Tr. AGM-2, Layer 2, Locus 1, 1.40 m depth.

**PRL-1297. BRW levels** **2140 ± 100**

Charcoal, Tr. AGM-2, Layer 3, Locus 0′–1′, 1.55 m depth.

**PRL-1298. BRW levels** **2240 ± 130**

Charcoal, Tr. AGM-2, Layer 3, Locus 0′–1′, 1.90 m depth.

**PRL-1299. Black and Red Rouletted Wares levels** **2260 ± 100**

Charcoal, Tr. AGM-2, Layer 5, Locus I′–II′, 2.80 m depth.

**PRL-869. Bahiri BRW period** **2540 ± 180**

Charcoal from Bahiri (23°60′N, 88°10′E), Birbhum dist., Tr. BHR III, Layer 4, 1.50 m depth; subm. by D. K. Chakrabarti; Sample 4.

### Balu series, Haryana

Balu, Jind dist.; subm. by S. Bhan, Kurukshetra Univ., Dept. Archaeol., Haryana.

*Comment*: dates provide Bronze Age chronology.

**PRL-985. Bronze Age culture** **2330 ± 100**

Charcoal, Tr. Q5, 0.6 m depth; Sample 2.

**PRL-989. Bronze Age culture** **3250 ± 150**

Charcoal, Tr. Q5, Layer 11, 1.5 m depth; Sample 6.

**PRL-1237. Beehive, Ceramic period** **1370 ± 100**

Shells from Beehive (12°25′N, 92°53′E), Middle Andaman dist., Andaman Islands, Tr. East, Layer Basal III, 1.2 m depth; subm. by Z. Cooper, Deccan Coll., Pune, Maharashtra; Sample 1.

*Comment*: dates ceramic period.

**PRL-792. Bhimbetka, Acheulian industry** $\mathbf{15{,}110\,^{+340}_{-330}}$

Calcium carbonate from Bhimbetka, Raisen dist., Tr. BTK III F23, Layer 5, 1.21–1.25 m depth; subm. by V. N. Misra, Deccan College, Pune; Sample BTK 13.

*Comment*: date is too young for the Acheulian.

### Chigargunta series, Andhra Pradesh

Chigargunta, Chittoor dist., subm. by G. Biksham, Chigargunta Gold Project, Sanganapalle, Andhra Pradesh.

*Comment*: dates gold mine.

**PRL-1187. Gold mine** **1270 ± 110**

Charcoal, Sample CCA-1.

**PRL-1188. Gold mine** **1050 ± 110**

Half-burned wood, Sample CCA-2.

**PRL-687. Dangawada Malwa culture** **3810 ± 140**

Charcoal from Dangawda, Ujjain dist., Tr. IV, Layer 9, 1.95 m depth; subm. by M. P. Khare, Dept. Archaeol., Madhya Pradesh, Bhopal; Sample 11.

*Comment*: dates Malwa culture deposits at site.

**PRL-919. Fatehganj** **140 ± 90**

Wood from Fatehganj (22°N, 72°3′E), Vadodara dist.; subm. by B. G. Sharma, Jyoti Ltd., PO Chemical Industries, Baroda; Sample RD/X/83.

*Comment*: dated to learn age of tree.

### Hatikra series, West Bengal, India

Hatikra (23°49′N, 87°35′E), Birbhum dist., West Bengal; subm. by N. C. Ghosh, Visva Bharati, Santiniketan, West Bengal.

*Comment*: samples dated to establish chronology of Iron Age site in West Bengal.

**PRL-1189. Iron Age** **1400 ± 90**

Charcoal, Tr. A′, Layer 3, 80 cm depth.

**PRL-1190. Iron Age** **1310 ± 90**

Charcoal, Tr. A′, Layer 5, 1.22 cm depth.

**PRL-1191. Iron Age** **2870 ± 120**

Charcoal, Tr. A′, Layer 6, 1.92 cm depth.

**PRL-1192. Iron Age** **900 ± 100**

Charcoal, Tr. XA′, Layer 3, 38 cm depth.

**PRL-1193. Iron Age** **1540 ± 130**

Charcoal, Tr. XA′, Layer 4, 66 cm depth.

**PRL-1194. Iron Age** **1480 ± 90**

Charcoal, Tr. XA′, Layer 4, 66 cm depth.

**PRL-1195. Iron Age** **1220 ± 130**

Charcoal, Tr. B′, Layer 3, 81 cm depth.

### Hulas series, Uttar Pradesh

Hulas (28°43′N, 77°22′E), Saharanpur dist.; subm. by K. N. Dikshit, Archaeol. Survey of India, New Delhi.

*Comment*: dates late Harappan phase.

**PRL-1031. Harappan period** **3840 ± 110**

Charcoal, Tr. XH8, Qd 1, Layer 8, 1.36 m depth; Sample 11.

**PRL-1032. Harappan period** **4380 ± 150**

Charcoal, Tr. XH8, Qd 1, Layer 8, 1.35 m depth; Sample 12.

**PRL-1097. Ingaldhal copper mines** **2010 ± 110**

Wood from Ingaldhal mines (14°11′N, 76°26′E), Chitradurga dist., 47 m depth; subm. by R. Shankar, Mangalore Univ., Mangalagangotri, Karnataka; Sample Inwood 2.

*Comment*: dates operation of old mine.

**Kakrahta series, Madhya Pradesh**

Kakrahta (28°23′N, 73°2′E), Jabalpur dist., subm. by V. K. Bajpai, Archaeol. Museum, eastern region, Japalpur.

*Comment*: dates early historic site.

**PRL-1051. Maurya Sunga period** **2870 ± 120**

Charcoal, Tr. KRT-I, Layer 10, 1.96 m depth; Sample 9.

**PRL-1054. Maurya Sunga period** **2310 ± 110**

Charcoal, Tr. KRT-I, Layer 11, 2.33 m depth; Sample 15.

**Khairadih series, Uttar Pradesh**

Khairadih (26°10′N, 83°51′E), Ballia dist.; subm. by V. Tripathi, Banaras Hindu Univ., Banaras.

*Comment*: dates beginning of cultural habitation at the site.

**PRL-1049. BRW period** **2890 ± 150**

Charcoal, Tr. KDH3, D′1, Layer 9, 6.48 m depth.

**PRL-1050. Northern Black Polished Ware (NBPW) period** **2060 ± 150**

Charcoal, Tr. KDH3, C′5, Layer 2, 1.67–2.55 m depth.

**PRL-929. Khetri, old mine** **340 ± 80**

Wood from Khetri (28°00′N, 75°51′E), Sikar dist., 20 m depth; subm. by D. K. Chakrabarti; Sample 3.

*Comment*: dates mine at Khetri.

**PRL-927. Khohdariba, old mine** **Modern**

Wood from Khohdariba (27°10′N, 76°24′E), Alwar dist.; subm. by D. K. Chakrabarti; Sample 1.

*Comment*: sample shows modern activity.

**Manjhi series, Bihar**

Manjhi (25°49′50″N, 84°55′E), Sasan dist., Bihar; subm. by T. N. Roy, Banaras Hindu Univ.

*Comment*: samples date different cultural periods at site.

**PRL-979. Period III** **1670 ± 130**

Charcoal, 3.07–3.60 m depth.

**PRL-980. NBPW period** **1930 ± 140**

Charcoal, 6.56–6.62 m depth.

**PRL-983. NBPW period** **2350 ± 140**

Charcoal, 9.65–9.94 m depth.

**PRL-854. Nagda, Upper Paleolithic** **>31,000**

Ostrich eggshells from Nagda, Ujjain dist., 4 m depth; subm. by the late V. S. Wakankar, Inst. Rock Art, Ujjain.

*Comment*: dates Upper Paleolithic settlement and art activity.

**PRL-914. Nagda, palaeosol** **$10{,}120 \, ^{+280}_{-270}$**

Soil carbonate and organic fraction from Nagda, Layer 9, depth 0.3 m; subm. by H. Raghavan, Deccan Coll., Pune; Sample 667.

*Comment*: dates palaeosol.

**PRL-816. Pythpatan, Neolithic** **4190 ± 140**

Charcoal from Pythpatan (34°12′N, 74°21′E), Baramula dist.; subm. by R. K. Pant, PRL, Ahmedabad; Sample 1.

*Comment*: dated for age of industry.

**PRL-928. Rajpur Dariba, old mine** **2390 ± 140**

Wood from Rajpur Dariba (24°57′N, 74°10′E), Udaipur dist.; subm. by D. K. Chakrabarti; Sample 2.

*Comment*: dates Dariba copper mine.

**PRL-1196. Ramgada, Upper Paleolithic culture** **>31,000**

Ostrich eggshells from Ramgada, Mandsaur dist., 0.28 m depth; subm. by the late V. S. Wakankar, Bharat Kala Bhavan, Ujjain, Madhya Pradesh.

*Comment*: dates Upper Paleolithic culture at site.

### Rojdi series, India

Rojdi (21°52′N, 70°55′E), Rajkot dist., Gujarat State, India; subm. by M. H. Raval, Gujarat State Dept. Archaeol., Ahmedabad and G. L. Possehl, Univ. Pennsylvania, Philadelphia.

*Comment*: samples dated to study Rojdi southern extension and post-urban phase (Table 1).

TABLE 1. Charcoal Samples from Rojdi Area of Rajkot District, Gujarat, India

| PRL no. | Identification no. | Depth (cm) | $^{14}$C yr (B.P.) |
|---|---|---|---|
| -1081 | 5241 | 46–52 | 2360 ± 210 |
| -1084 | 2218 | 86 | 3700 ± 150 |
| -1282 | 10481 | 131 | 3470 ± 140 |
| -1281 | 10483 | 140 | 3520 ± 110 |
| -1083 | 2248 | 150–160 | 3870 ± 120 |
| -1088 | 10126 | 190–220 | 3770 ± 120 |
| -1283 | 10763 | 207 | 3980 ± 100 |
| -1089 | 10161 | 236–243 | 3870 ± 120 |
| -1093 | 10137 | 237–243 | 3920 ± 110 |
| -1091 | 10148 | 236–244 | 4150 ± 110 |
| -1285 | 10769 | 257 | 3740 ± 140 |
| -1087 | 10173 | 244–276 | 4010 ± 110 |
| -1284 | 10768 | 263 | 3810 ± 100 |
| -1085 | 10184 | 280–288 | 4020 ± 110 |

### Sanghol series, Panjab, India

Sanghol (30°47′N, 76°23′E), Ludhiana dist., Panjab; subm. by R. C. Gaur, Archaeol. Survey India, Purana Qila, New Delhi.

**PRL-1269. Early Kushan period** **2070 ± 130**

Charcoal, Tr. BX-1, Layer 24, 5.45 m depth.

**PRL-1271. Early Kushan period** **1550 ± 120**

Charcoal, Tr. BX-1, Layer 20, 4.7 m depth.

**PRL-1274. Early Kushan period** **2500 ± 100**

Charcoal, Tr. D-3, Layer 15, 2.14 m depth.

**PRL-1277. Early Kushan period** **2250 ± 120**

Charcoal, Tr. XB2, Layer 8, 3.45 m depth.

### Semthan series, India

Semthan, Anantnag dist.; subm. by R. S. Bisht, Archaeol. Survey, India, Baroda.

**PRL-941. Pre-Northern Black Polished Ware (NBPW), Period I** **2200 ± 140**

Charcoal, Layer 34; Sample SMN-81/CC-25.

**PRL-945. NBPW, Period II** **2280 ± 110**

Charcoal, Layer 33; Sample SMN-81/CC-24.

**PRL-946. NBPW, Period II** **1880 ± 120**

Charcoal, Layer 32; Sample SMN-81/CC-17.

**PRL-959. Indo-Greek, Period III** **1730 ± 130**

Charcoal, Layer 23; Sample SMN-81/CC-9.

**PRL-778. Singh-Bhagwantpur, Early Historic period** **3010 ± 90**

Charcoal from Singh-Bhagwantpur (35°53′N, 76°33′E), Rupnagar dist., Tr. 30-T, Layer 6, 2.72 m depth; subm. by Y. D. Sharma, Dept Archaeol., Panjab Univ., Chandigarh; Sample SBP-30-796.

*Comment*: dates confirm earlier chronology.

### Vallam series, Tamil Nadu

Vallam (10°43′N, 79°4′E), Thanjavur dist., Tamil Nadu; subm. by Y. Subbarayalu, Dept. Epigraphy, Tamil Nadu.

*Comment*: dates show transition of different cultures.

**PRL-1108. BRW period** **1300 ± 100**

Charcoal, Tr. VLM-1, Layer 8, Locus II′–IV, 155 cm depth.

**PRL-1109. Early Historic period** **2900 ± 100**

Charcoal, Tr. VLM-1, Layer 9, Locus II–IV, 187–192 cm depth.

**PRL-1110. Early Historic period** **2840 ± 140**

Charcoal, Tr. VLM-1, Layer 9, Locus 0–11, 200 cm depth.

**PRL-1111. Early Historic period** **2360 ± 120**

Charcoal, Tr. VLM-1, Layer 9, Locus III′–IV′, 205–210 cm depth.

**PRL-1238. Yarata Nala, basal layers** **1470 ± 100**

Shells, basal layer, 1.5 m depth; subm. by Z. Cooper; Sample 2.

*Comment*: date confirms contemporaneity of site with Beehive midden; see PRL-1237, above.

### Zawar Mala series, Rajasthan

Zawar Mala (24°19–45′N, 73°40′E), Udaipur dist.; subm. by V. L. Upadhyaya, Hindustan Zinc Ltd., Zawar.

*Comment*: dates ancient mining activity in area.

**PRL-933. Ancient mine** **1940 ± 140**

Charcoal, Sample ZM/4.

**PRL-934. Ancient mine** **730 ± 130**

Charcoal, Sample ZM/7.

**PRL-935. Ancient mine** **820 ± 130**

Charcoal, Sample ZM/8.

*Nepal*

**Dumakhad series, Kathmandu**

Dumakhad, Kathmandu dist.; subm. by M. P. Khanal, Research Centre, Nepal Asian Studies, Kirtipur.

*Comment*: dates provide historical chronology.

**PRL-1073. Historic levels** **590 ± 90**

Charcoal, Tr. A, Layer 1, 0.32 m depth.

**PRL-1074. Early historic levels** **1360 ± 90**

Charcoal soil, Tr. F, Layer 3, 1.80 m depth.

*Sri Lanka*

**PRL-976. Alu-lena, geometric microliths** **9410 ± 150**

Charcoal from Alu-lena (7°15′N, 80°25′E), Kegalle dist., Tr. AAX, Layer 3, 1.5 m depth; subm. by S. U. Deraniyagala, Dept. Archaeol., Colombo; Sample ALK(3).

*Comment*: dates show considerable scatter; some dates seem quite early for context.

**Beli-lena Kitulgala series**

Beli-lena, Kitugala (7°N, 80°25′E), Kegalle dist., Sri Lanka; subm. by S. U. Deraniyagala.

**PRL-1011. Geometric microliths** $\mathbf{14{,}100\,^{+300}_{-290}}$

Charcoal, Tr. 12J; 131, Layer IIIa1 and IIIa2, 168–190 cm depth.

**PRL-1012. Geometric microliths** **3170 ± 120**

Charcoal, Tr. 20A, Layer IIIa3, 164–168 cm depth.

**PRL-1013. Geometric microliths** $\mathbf{17{,}870\,^{+570}_{-530}}$

Charcoal, Tr. 12I, Layer IIIb1, 145–164 cm depth.

**PRL-1015. Geometric microliths** $\mathbf{24{,}520\,^{+1500}_{-1270}}$

Charcoal, Tr. 5F, Layer IIIc2, 130–141 cm depth.

**PRL-1019. Geometric microliths** **8660 ± 200**

Charcoal, Tr. 13I, Layer IVb3, 68–90 cm depth.

Batadomba cave (8°N, 82°E), Ratnapura dist.; subm. by S. U. Deraniyagala.

*Comment*: samples date non-geometric microliths.

**PRL-859. Upper Paleolithic** **$13{,}880\ ^{+370}_{-360}$**

Charcoal, Tr. 16g, Layer 6A, 2 m depth; Sample Bd 16g 6A.

**PRL-860. Upper Paleolithic** **$13{,}130\ ^{+440}_{-420}$**

Charcoal, Tr. 16H, Layer 5, 1.7 m depth; Sample Bd 16H5.

**PRL-828. Maduru-Oya Reservoir dam, ancient reservoir** **1380 ± 130**

Charcoal from Madur-Oya Reservoir dam, Polonnaruwa dist., 3 m depth; subm. by S. U. Deraniyagala; Sample 2.

*Comment*: dates irrigation technology.

## GEOLOGICAL SAMPLES

*India*

### Arabian Sea sediment series

Marine sediments from the shelf region of Arabian Sea, Samples PRL-1307 to -1320 subm. by M. V. S. Gupta, Natl. Inst. Oceanog. (NIO), Goa and PRL-1321 to -1327 subm. by R. Shankar.

*Comment*: samples dated to study sedimentation rate, paleoclimate and biostratigraphy of foraminifera (Table 2).

TABLE 2. Sediments from Arabian Sea

| PRL no. | Identification no. | Depth (m) | Lat (N) | Long (E) | $^{14}$C yr (B.P.) |
|---|---|---|---|---|---|
| -1307 | Sta 3943 | 0.6–0.7 | 21°4.5′ | 69°7′ | 4150 ± 120 |
| -1308 | Sta 3943 | 0.8–0.9 | 21°4.5′ | 69°7′ | 5610 ± 130 |
| -1310 | Sta 3944 | Top | 21°20′ | 69°30′ | 8100 ± 130 |
| -1314 | Sta 3952 | 0.4–0.45 | 21°53′ | 68°2′ | 4720 ± 100 |
| -1315 | Sta 3952 | 1.0–1.10 | 21°53′ | 68°2′ | 4560 ± 100 |
| -1320 | Sta 3958 | 1.5 (bottom) | 22°41′ | 68°23′ | $10{,}050\ ^{+240}_{-230}$ |
| -1321 | CA-65-10 | 0.65–0.70 | 12°10′ | 72°15′ | 11,620 ± 250 |
| -1322 | Ca-10-15 | 0.1–0.15 | 12°14′ | 72°15′ | 4680 ± 110 |
| -1323 | CA-40-45 | 0.4–0.45 | 12°14′ | 72°15′ | $12{,}550\ ^{+440}_{-410}$ |
| -1325 | CA-70-75 | 0.7–0.75 | 12°14′ | 72°15′ | $17{,}140\ ^{+350}_{-330}$ |
| -1326 | CA-95-100 | 0.95–1.0 | 12°14′ | 72°15′ | $25{,}380\ ^{+1190}_{-1040}$ |
| -1327 | CA-115-120 | 1.15–1.20 | 12°14′ | 72°15′ | $29{,}150\ ^{+2600}_{-1960}$ |

**PRL-909. Arabian Sea, phosphorite deposits** **$10{,}720\ ^{+400}_{-380}$**

Phosphorite deposits from southwest of Arabian Sea off-shelf region; subm. by D. V. Borole, NIO, Panaji, Goa.

*Comment*: dates phosphorite.

**Bap Rann series, Rajasthan**

Organic-rich material from Salt Lake, Bap Rann; subm. by H. Raghavan.

*Comment*: dates site.

**PRL-916. Sediment** **Modern**

Organic material, 1.3–1.6 m depth; Sample 5.

**PRL-917. Sediment** **9240 ± 150**

Organic material, 1.8–2.05 m depth; Sample 6.

**PRL-1178. Birohar, mud** **5120 ± 120**

Calcite from Birohar (28°35′N, 76°22′E), Bhimani dist., 0.9–1.0 m depth; subm. by S. B. Bhatia, Geol. Dept., Panjab Univ., Chandigarh.

*Comment*: calcite dated for age of microfauna.

**Carlesberg Ridge series, Arabian Sea**

Sediment core from Carlesberg Ridge (4°59.968′N, 65°14.062′E); subm. by D. V. Borole.

**PRL-1257. Sediment** **$27{,}980\ ^{+3800}_{-2570}$**

Organic material, 0.1–0.15 m depth.

**PRL-1258. Sediment** **$23{,}790\ ^{+920}_{-830}$**

Organic material, 0.3–0.35 m depth.

**PRL-1259. Sediment** **$27{,}610\ ^{+1450}_{-1230}$**

Organic material, 0.35–0.4 m depth.

**PRL-1260. Sediment** **> 31,000**

Organic material, 0.5–0.55 m depth.

**PRL-922. Drgli Bakurpara, organic-rich clay** **460 ± 100**

Organic clay from Drgli Bakurpara (25°58′45″N, 91°03′45″E), Godpara dist., Assam; subm. by K. K. Sinha, Geol. Survey India (GSI), Shillong.

*Comment*: dated to study Quaternary stratigraphy of lower Brahmaputra basin.

### Kashmir Valley paleoclimatic series

Deposits from various locations in Kashmir valley (Tables 3 and 4); subm. by D. P. Agrawal (Kusumgar, Agrawal & Krishnamurthy 1980; Kusumgar *et al.* 1986).

TABLE 3. Dates of Kashmir Valley Loess Deposits

| Site name | Horizon (Palaeosol) | PRL no. Organic (O); Carbonate (C) | Lat (N) | Long (E) | $^{14}$C yr (B.P.) |
|---|---|---|---|---|---|
| Burzahom | 2 | -585-O | 34°10′ | 74°53′ | > 31,000 |
| Burzahom | 3 | -586-O | 34°10′ | 74°53′ | > 31,000 |
| Burzahom | 3 | -588-C | 34°10′ | 74°53′ | $14{,}000^{+290}_{-280}$ |
| Burzahom | 1 | -590-O | 34°10′ | 74°53′ | $18{,}460^{+820}_{-740}$ |
| Burzahom | 1 | -590-C | 34°10′ | 74°53′ | $17{,}060^{+350}_{-340}$ |
| Burzahom | 1 | -591-C | 34°10′ | 74°53′ | $20{,}340^{+1320}_{-1130}$ |
| Burzahom | 1 | -593-O | 34°10′ | 74°53′ | $18{,}890^{+830}_{-750}$ |
| Burzahom | 1 | -593-C | 34°10′ | 74°53′ | $15{,}700^{+370}_{-360}$ |
| Burzahom | 1 | -594-C | 34°10′ | 74°53′ | $20{,}430^{+920}_{-820}$ |
| Burzahom | 1 | -611-C | 34°10′ | 74°53′ | $20{,}190^{+570}_{-530}$ |
| Burzahom | 3 | -1038-O | 34°10′ | 74°53′ | > 31,000 |
| Burzahom | 3 | -643-O | 34°10′ | 74°53′ | $30{,}520^{+1800}_{-1470}$ |
| Burzahom | 4 | -829-C | 34°10′ | 74°53′ | $14{,}170^{+500}_{-470}$ |
| Dilpur | 1 | -824-C | 33°56′ | 74°57′ | 10,340 ± 220 |
| Dilpur | 1 | -825-O | 33°56′ | 74°57′ | 14,490 ± 310 |
| Dilpur | 2 | -826-C | 33°56′ | 74°57′ | $21{,}840^{+1150}_{-1000}$ |
| Dilpur | – | -760-O | 33°56′ | 74°57′ | > 31,000 |
| Dilpur | – | -830-O | 33°56′ | 74°57′ | $17{,}740^{+630}_{-580}$ |
| Garhi Burzahom | 3 | -592-O | 34°10′ | 74°53′ | $26{,}340^{+2010}_{-1610}$ |
| Kanier | 3 | -1041-C | 33°56′30″ | 74°44′15′ | $26{,}900^{+1360}_{-1160}$ |
| Kanier | 3 | -1041-O | 33°56′30″ | 74°44′15′ | > 31,000 |
| Kanier | 2 | -1042-O | 33°56′30″ | 74°44′15′ | > 31,000 |
| Kanier | 1 | -1043-O | 33°56′30″ | 74°44′15′ | $27{,}380^{+2410}_{-1850}$ |
| Khanchikhol | 1 | -848-O | 33°47′13″ | 74°50′7″ | 5930 ± 170 |
| Khanchikhol | 3 | -849-O | 33°47′13″ | 74°50′7″ | $25{,}190^{+1740}_{-1430}$ |
| Khanchikhol | 3 | -1045-O | 33°47′13″ | 74°50′7″ | > 31,000 |
| Khanchikhol | 3 | -1045-C | 33°47′13″ | 74°50′7″ | $26{,}490^{+1700}_{-1400}$ |
| Khanchikhol | 1 | -1206-O | 33°47′13″ | 74°50′7″ | 5140 ± 110 |
| Khanchikhol | 1 | -1286-O | 33°47′13″ | 74°50′7″ | 6040 ± 110 |
| Khanchikhol | 2 | -1287-O | 33°47′13″ | 74°50′7″ | $23{,}300^{+720}_{-660}$ |
| Khanchikhol | 3 | -1288-O | 33°47′13″ | 74°50′7″ | >31,000 |
| Malpura | 1 | -851-O | 34°4′30″ | 74°19′45″ | 6500 ± 190 |

TABLE 3. (Continued)

| Site name | Horizon (Palaeosol) | PRL no. Organic (O) Carbonate (C) | Lat (N) | Long (E) | $^{14}$C yr (B.P.) |
|---|---|---|---|---|---|
| Olchibagh | 1 | -597-C | 34°4′30″ | 74°19′45″ | $24{,}960^{+1780}_{-1460}$ |
| Olchibagh | 2 | -598-C | 34°4′30″ | 74°19′45″ | $21{,}200^{+630}_{-580}$ |
| Olchibagh | 2 | -598-O | 34°4′30″ | 74°19′45″ | $12{,}560^{+450}_{-430}$ |
| Pakharpur | 1 | -627-O | 33°48′ | 74°47′ | $27{,}630^{+1350}_{-1160}$ |
| Pakharpur | 2 | -628-O | 33°48′ | 74°47′ | > 31,000 |
| Pattagarh | 2 | -1210-O | 33°58′6″ | 74°58′5″ | > 31,000 |
| Peehru | 1 | -1211-O | 33°44′ | 75°11′ | > 31,000 |
| Puthkhah | 2 | -617-O | 34°14′ | 74°21′ | $25{,}800^{+1100}_{-960}$ |
| Puthkhah | 2 | -617-C | 34°14′ | 74°21′ | $28{,}560^{+1560}_{-1300}$ |
| Puthkhah | 1 | -618-O | 34°14′ | 74°21′ | $18{,}550^{+600}_{-550}$ |
| Puthkhah | 1 | -618-C | 34°14′ | 74°21′ | > 31,000 |
| Romu | 1 | -629-O | 33°53′ | 74°50′ | 5660 ± 120 |
| Romu | 2 | -630-O | 33°53′ | 74°50′ | 4030 ± 130 |
| Romu | 3 | -631-O | 33°53′ | 74°50′ | > 31,000 |
| Romu | 4 | -632-O | 33°53′ | 74°50′ | $22{,}070^{+1000}_{-890}$ |
| Romu | 5 | -1034-O | 33°53′ | 74°50′ | $28{,}240^{+1530}_{-1290}$ |
| Saki Paparian | 1 | -595-C | 34°49′ | 75°07′ | > 31,000 |
| Saki Paparian | 2 | -596-O | 34°49′ | 75°07′ | > 31,000 |
| Saki Paparian | 3 | -596-C | 34°49′ | 75°07′ | > 31,000 |
| Shupian | 2 | -1217-O | 33°42′14″ | 75°49′9″ | > 31,000 |
| Tilsur | – | -850-O | 33°52′ | 74°47′ | $20{,}740^{+1050}_{-980}$ |
| Tsrar Sharif | 1 | -624-O | 33°51′ | 74°46′ | > 31,000 |
| Tsrar Sharif | 2 | -625-O | 33°51′ | 74°46′ | > 31,000 |
| Tsrar Sharif | 3 | -626-O | 33°51′ | 74°46′ | > 31,000 |
| Wagahoma | 1 | -1205-O | 33°49′46″ | 75°6′38″ | > 31,000 |
| Zadur | – | -635-O | 33°55′ | 74°51′ | $15{,}360^{+360}_{-350}$ |
| Zadur | – | -636-O | 33°55′ | 74°51′ | $26{,}660^{+1240}_{-1070}$ |

**PRL-773. Khodri-ride-inchibra, carbonaceous clay > 31,000**

Carbonaceous clays from Khodri-ride-inchibra tunnel (30°33′N, 77°48′E), Sirmur dist.; subm. by P. J. Jalote, Geol. Survey India, Nagpur; Sample 3.

*Comment*: dates movement along Krol thrust in Himalayas.

### Matikhad series, Assam

Semi-carbonized wood from Matikhad (27°17′30″N, 95°43′10″E), Dibrugarh dist.; subm. by A. B.

TABLE 4. Dates on Other Kashmir Deposits

| Site name | Material depth | PRL No. Organic (O) Carbonate (C) | Lat (N) | Long (E) | $^{14}$C yr (B.P.) |
|---|---|---|---|---|---|
| Anchar Lake | Organic mud<br>0.6–1.2 m | -813-O | 34°6′ | 74°43′N | Modern |
| Anchar Lake | Organic mud<br>1.2–1.7 m | -814-O | 34°6′ | 74°43′N | 1180 ± 110 |
| Anchar Lake | Organic mud<br>6.9–7.2 m | -815-O | 34°6′ | 74°43′N | 930 ± 120 |
| Anchar Lake | Organic mud<br>7.5–7.8 m | -812-O | 34°6′ | 74°43′N | 4030 ± 140 |
| Anchar Lake | Peat<br>6.3–6.6 m | -823-O | 34°6′ | 74°43′N | 2600 ± 120 |
| Anchar Lake | Mud<br>5.55–5.7 m | -864-O | 34°6′ | 74°43′N | 3390 ± 150 |
| Butapathri | Lake clay<br>1.9–1.4 m | -842-O | 34°4′30″ | 74°18′30″ | $10,640\ ^{+\,530}_{-\,310}$ |
| Butapathri | Lake clay<br>0.9–1.15 m | -847-O | 34°4′30″ | 74°18′30″ | 2140 ± 140 |
| Butapathri | Lake clay<br>0.65–0.9 m | -846-O | 34°4′30″ | 74°18′30″ | 990 ± 140 |
| Butapathri | Lake clay<br>0.15–0.65 m | -845-O | 34°4′30″ | 74°18′30″ | 1090 ± 130 |
| Butapathri | Lake clay<br>2.45–2.85 m | -843-O | 34°4′30″ | 74°18′30″ | $16,620\ ^{+\,570}_{-\,530}$ |
| Butapathri | Lake clay<br>1.65–2.15 m | -844-O | 34°4′30″ | 74°18′30″ | 8930 ± 210 |
| Jammu Cave | Stalactite | -831-C | – | – | 1540 ± 100 |
| Jammu Cave | Stalactite | -832-C | – | – | 1530 ± 150 |
| Jammu Cave | Stalactite | -833-C | – | – | 1100 ± 130 |
| Kolahoi | Wood | -1121-O | 34°12′ | 75°20′ | 150 ± 100 |
| Kolahoi | Wood | -1122-O | 34°12′ | 75°20′ | 810 ± 90 |
| Nadial Lake | Mud<br>2.0–2.5 m | -862-O | 33°41′ | 74°17′ | 2220 ± 140 |
| Nadial Lake | Mud | -863-O | 33°41′ | 74°17′ | 2440 ± 150 |

Goswami, Geol. Survey India, Shillong.

*Comment*: dating will facilitate understanding of biostratigraphy of formation.

**PRL-578. Wood** **$17,960\ ^{+490}_{-460}$**

Semi-carbonized wood, 2.54 m depth ; Sample SII9A.

**PRL-582. Wood** **$17,040\ ^{+660}_{-610}$**

Semi-carbonized wood, 2.54–2.58 m depth; Sample W/QG.

**PRL-583. Wood** **$16,800\ ^{+450}_{-430}$**

Semi-carbonized wood, 2.20–2.25 m depth; Sample W2/QG.

**PRL-1179. Misri, Marl** **4100 ± 120**

Marl from Misri (28°40′N, 76°17′E), Bhiwani dist.; subm. by S. B. Bhatia.

*Comment*: measured to date microfauna.

**PRL-1027. Mendipathar, dry wood** **1080 ± 100**

Wood from Mendipathar (25°50′–26°00′N, 90°35′–90°40′E), 3.30 m depth; Sample 4.1; subm. by B. K. Rastogi, NGRI, Hyderabad.

*Comment*: dated to determine interval between major earthquakes in area.

**Minicoy series, Union Territory of Lakshadweep**

Coral from Minicoy (80°17′N, 73°E); subm by S. K. Gulati, Indian Inst. Techn. (IIT), New Delhi.

*Comment*: dated to study effect of age on strength of material and degree of diagenesis.

**PRL-839. Coral** **Modern**

Coral from lagoon; Sample 4.

**PRL-840. Coral** **Modern**

Coral from lagoon; Sample 5.

**Nainital Lakes series, Uttar Pradesh**

Sediment core from dry bed of lakes (29°19.5–24′N, 79°25–35′E), Nainital dist.; subm by P. Sharma, PRL, Ahmedabad.

*Comment*: dated to study sedimentation rate of Nainital Lakes (Table 5).

TABLE 5. Sediments from Nainital Lakes District

| Lake | Depth (m) | PRL no. Organic (O) Carbonate (C) | Lat (N) | Long (E) | $^{14}$C yr (B.P.) |
|---|---|---|---|---|---|
| Kamal Tal | 5.30–5.50 | -1098-O | 29°24′ | 79°25′ | 6950 ± 150 |
| Kamal Tal | 3.60–3.80 | -1099-O | 29°24′ | 79°25′ | 4270 ± 120 |
| Kamal Tal | 2.80–3.00 | -1100-O | 29°24′ | 79°25′ | 4030 ± 160 |
| Kamal Tal | 1.70–1.90 | -1107-O | 29°24′ | 79°25′ | 3080 ± 100 |
| Kamal Tal | 2.20–2.40 | -1180-O | 29°24′ | 79°25′ | 3070 ± 100 |
| Kamal Tal | 0.60–0.80 | -1181-O | 29°24′ | 79°25′ | 880 ± 100 |
| Sukha Tal | 1.32–1.42 | -1105-O | 29°23′ | 79°32′ | 1280 ± 90 |
| Bharat Tal | 1.70–1.80 | -1106-O | 29°23′ | 79°32′ | 860 ± 90 |
| Garud Tal | 1.60–1.70 | -1120-O | 29°23′ | 79°32′ | 2920 ± 100 |
| Naukuchia Tal (relict section) | 0.8 | -1232-O | 29°20′ | 79°35′ | > 31,000 |

**Narara Bet series, Gujarat**

Coral reef rock from Narara Bet (22°29′N, 69°44′E), Jamnagar dist; subm. by S. K. Gulati.

*Comment*: dated to study effect of age on coral and degree of diagenesis.

**PRL-836. Coral reef rock** **5340 ± 170**

Coral, 2.0–2.5 m depth.

**PRL-837. Coral reef rock** **4520 ± 170**

Coral, 2.5–3 m depth.

**PRL-838. Okha R-station, coral reef rock** **Modern**

Coral from Okha R-station (22°28′N, 69°05′E), Jamnagar dist.; subm by S. K. Gulati.

*Comment*: same as above.

**PRL-915. Talchappar, sediment** **6620 ± 170**

Organic sediment from Talchappar, Churu dist., Rajasthan State, 1.77 m depth; subm. by H. Raghavan.

*Comment*: measured to date Holocene climatic changes.

**Tri Junction series, Rajasthan**

Caliche samples from Tri Junction (26°16′N, 72°19′E); subm. by R. V. Krishnamurthy, PRL, Ahmedabad.

**PRL-574. Caliche** $\mathbf{21{,}910\ ^{+540}_{-510}}$

Carbonate, Core no. C28, 0.7 m depth.

**PRL-575. Caliche** **> 31,000**

Carbonate, Core no. C29, 2.6 m depth.

**PRL-576. Caliche** **> 31,000**

Carbonate, Core no. C30, 3.0 m depth.

**PRL-577. Caliche** **> 31,000**

Carbonate, Core no. C31, 3.28–3.65 m depth.

**Tuticorin Harbor series, Tamil Nadu**

Limestone from Tuticorin Harbor (7.8°N, 78.2°E), Tirunelveli dist.; subm. by M. V. Guptha, NIO and Dona Paula.

*Comment*: dated to study sedimentology and micropaleontology.

**PRL-977. Limestone** $28,550^{+1320}_{-1140}$

**PRL-978. Limestone** $25,790^{+1750}_{-1430}$

**PRL-923. Uniew River, sediment** **730 ± 110**

Wood from Uniew River, E Khasi Hills dist., 4.0 m depth; subm. by K. K. Sinha.

*Comment*: dated to understand geomorphic setting of Meghalaya plateau.

**PRL-1023. Western continental shelf** $11,310^{+250}_{-240}$

Aragonite from the western continental shelf (14°00′N, 73°53′7″E); subm. by R. R. Nair, NIO and Dona Paula; Sample G/18/81(A).

**Ziro Valley River series, Arunachal Pradesh**

Organic material from Ziro Valley River, Subansin dist.; subm. by K. K. Sinha.

*Comment*: dated to establish Quaternary stratigraphy.

**PRL-924. Wood** **> 31,000**

Wood, 2 m depth; Sample 83E14/4/1.

**PRL-926. Peat** **> 31,000**

Peat; Sample 83E14/4/2.

*Italy*

**PRL-918. Civitavellhia, sediment** $10,830^{+360}_{-350}$

Carbonate from Civitavellhia (42°13′N, 11°27′E); subm. by J. C. Castagnoli, Inst. Cosmo-Geofisica, Obitorino, Italy.

*Comment*: dated to establish sedimentation rate.

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# TARTU RADIOCARBON DATES XII

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## INTRODUCTION

This list includes dates of geological samples measured using a single-channel liquid scintillation $^{14}$C counter at the Geochemical and Statistical Laboratory, Tartu, Estonia. Our modern standard is made of benzene enriched in $^{14}$C, and its activity is checked with NBS oxalic acid standard sample. Dates are given in conventional radiocarbon years, based on the Libby half-life of 5570 ± 30 years. A.D. 1950 is the reference year. Errors refer only to $1\sigma$ standard deviation calculated from count rates involved.

## GEOLOGICAL SAMPLES

### *Estonia*

### Nigula Bog series

Nigula bog reservation lies at SW border of coastal region of Estonia, 35 km S of Pärnu and 10 km E of coast of Riga Bay. Bog stretches N-S, 9 km long and 3–4 km wide. Five small islands are located west of bog, covered with wood. Samples coll. 1973 by E. Ilves and A. Sarv (Nigula 3, 4), and in early 1980s, by M. Ilomets. (Nigula 19, 24, 42, 46, 51) (Ilomets, Ilves & Rajamäe 1984). Figure 1 shows locations where samples were collected.

*Nigula 3*

**TA-1116. Nigula 3** **500 ± 60**

Raised peat from 130–140 cm depth.

**TA-1115. Nigula 3** **1820 ± 60**

Raised peat from 236–246 cm depth.

**TA-1113. Nigula 3** **2190 ± 70**

Raised peat from 330–340 cm depth.

**TA-316. Nigula 3** **4330 ± 70**

Raised peat with charcoal remains from 408–412 cm depth.

**TA-1111. Nigula 3** **2290 ± 80**

Raised peat from 416–426 cm depth.

**TA-1110. Nigula 3** **7230 ± 70**

Fen peat from 458–468 cm depth.

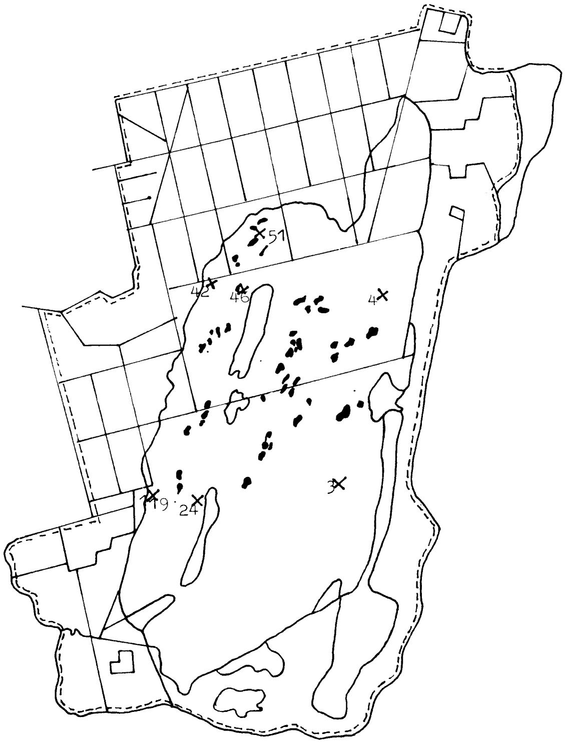

Fig. 1. Map of Nigula Bog showing locations where samples were collected. Numbers correspond to samples listed in text.

**TA-331. Nigula 3** **7080 ± 70**

Fen peat from 465–475 cm depth.

**TA-1108. Nigula 3** **7290 ± 90**

Fen peat from 507–517 cm depth.

**TA-403. Nigula 3** **7500 ± 70**

Fen peat with weakly decomposed *Phragmites* layer from 520–530 cm depth.

*Nigula 4*

**TA-569. Nigula 4** **4590 ± 80**

Mesotrophic peat from 360–370 cm depth.

**TA-570. Nigula 4** **4680 ± 80**

Mesotrophic peat from 370–380 cm depth.

**TA-571. Nigula 4** **5010 ± 70**

Mesotrophic peat from 455–465 cm depth.

**TA-572. Nigula 4** **6010 ± 80**

Mesotrophic peat from 479–480 cm depth.

**TA-480. Nigula 4** **6000 ± 70**

Mesotrophic peat from 480–490 cm depth.

**TA-410. Nigula 4** **8600 ± 90**

Fen peat from 500–510 cm depth.

*Nigula 19*

**TA-1150. Nigula 19** **280 ± 60**

Raised peat from 92–97 cm depth.

**TA-1158. Nigula 19** **300 ± 60**

Raised peat from 97–102 cm depth.

**TA-1151. Nigula 19** **420 ± 60**

Raised peat from 180–190 cm depth.

**TA-1152. Nigula 19** **940 ± 60**

Raised peat from 204–214 cm depth.

**TA-1153. Nigula 19** **1600 ± 60**

Raised peat from 230–240 cm depth.

**TA-1154. Nigula 19** **1700 ± 60**

Raised peat from 258–268 cm depth.

**TA-1155. Nigula 19** **1670 ± 70**

Raised peat from 300–305 cm depth.

**TA-1156. Nigula 19** **1960 ± 60**

Raised peat containing birch bark from 346–350 cm depth.

**TA-1157. Nigula 19** **2540 ± 60**

Raised peat from 358–363 cm depth.

*Nigula 24*

**TA-1197. Nigula 24** **360 ± 60**

Raised peat from 71–76 cm depth.

**TA-1198. Nigula 24** **870 ± 70**

Raised peat from 163–168 cm depth.

*Nigula 46*

**TA-1206. Nigula 46** **Modern**

Raised peat from 50–60 cm depth.

**TA-1207. Nigula 46** **590 ± 70**

Raised peat from 134–144 cm depth.

**TA-1208. Nigula 46** **1550 ± 70**

Raised peat from 240–250 cm depth.

**TA-1209. Nigula 46** **1590 ± 70**

Raised peat from 273–283 cm depth.

*Nigula 51*

**TA-1199. Nigula 51** **160 ± 50**

Raised peat from 80–90 cm depth.

**TA-1200. Nigula 51** **820 ± 60**

Raised peat from 152–160 cm depth.

**TA-1201. Nigula 51** **1100 ± 70**

Raised peat from 220–230 cm depth.

**TA-1202. Nigula 51** **1340 ± 60**

Raised peat from 265–275 cm depth.

**TA-1203. Nigula 51** **1570 ± 80**

Raised peat from 328–338 cm depth.

**TA-1204. Nigula 51** **1610 ± 60**

Raised peat from 380–387 cm depth.

**TA-1205. Nigula 51** **4130 ± 60**

Mesotrophic peat from 424–431 cm depth.

*Nigula 42*

**TA-1210. Nigula 42** **410 ± 60**

Raised peat from 100–110 cm depth.

**TA-1212. Nigula 42** **1630 ± 70**

Raised peat from 346–356 cm depth.

**TA-1213. Nigula 42** **3590 ± 70**

Raised peat from 453–463 cm depth.

**Nohipalu Valgjärv series**

Valgjärv Lake lies 3.5 km S of Veriora settlement (SE Estonia) in pine forest (6.3 $ha^2$, max. depth 11.7 m). Lake is government protected (Mäemets 1977). In N littoral peat of lake, at 0.6–0.7 m depth, juniper stumps were found and $^{14}C$ dated. Soil humus collected near N coast of lake and deposits from small (50 m diam.) round bog, SE of lake, were also dated. Samples coll. by A. Mäemets, E. Ilves and M. Pork, Inst. Zoology and Botany, Tartu.

**TA-577. Nohipalu Valgjärv** **3130 ± 80**

Juniper stumps.

**TA-693. Nohipalu Valgjärv** **3120 ± 80**

Juniper stumps.

**TA-787. Nohipalu Valgjärv** **3300 ± 80**

Juniper stumps.

**TA-698. Nohipalu Valgjärv** **3060 ± 80**

Juniper stumps.

**TA-567. Nohipalu Valgjärv** **5980 ± 200**

Soil layer containing humus.

**TA-753. Nohipalu Valgjärv** **3600 ± 80**

Fen peat from 330–340 cm depth.

**TA-754. Nohipalu Valgjärv** **3900 ± 60**

Sapropelized fen forest peat from 340–350 cm depth.

**TA-755. Nohipalu Valgjärv** **4220 ± 70**

Aleuritic bog deposits with black layers from 360–370 cm depth.

## Estonian Lakes series

*Saadjärv Lake.* The largest lake in the drumlin landscape of Estonia, 53.4 m asl, lies on the border of Tartumaa and Jõgevamaa districts, 16 km N of Tartu. It is about 700 $ha^2$, 6 km long and 1.8 km wide. Maximum depth is 25 m in the SE part of the lake. Average depth is 8 m. The lake is government protected (Mäemets 1977). Samples coll. 1977 by E. Ilves and A. Lindpere, Inst. Zoology and Botany, Tartu.

**TA-1009. Saadjärv** **1570 ± 60**

Surface layer of lake sediments, 15 cm thick, under water, 22 m deep.

*Udsu Lake.* Udsu is the deepest lake of the Sakala upland (Valgamaa Dist., 3 km S of Koorküla). The lake lies NE-SW, 76 m asl, 6.2 $ha^2$. Maximum depth is 30.25 m (Mäemets 1977). Samples coll. 1978 by E. Ilves and A. Lindpere.

**TA-1053. Udsu Lake** **640 ± 60**

Surface layer, 15 cm thick, under water, 24 m deep.

*Petajärv Lake.* Petajärv Lake lies in the Valgamaa Dist., 35 km SE of Koorküla. The lake lies NW-SE, 67 m asl, 3.6 $ha^2$, 22 m depth (Mäemets 1977). Samples coll. 1978 by E. Ilves and A. Lindpere.

**TA-1052. Petajärv Lake** **Modern**

Surface layer of lake sediments, 7 cm thick, under water, 21.5 m deep.

*Tollari Lake.* Tollari Lake lies in the Valgamaa Dist., 1.5 km W of Karula, 94.2 m asl, 4.5 $ha^2$, maximum depth, 9.9 m. The lake is surrounded by cultivated land (Mäemets 1977). Samples coll. by E. Ilves and A. Lindpere.

**TA-1010. Tollari Lake** **720 ± 60**

Surface layer of lake sediments, 5 cm thick, under water, 8.3 m deep.

### *The High Caucasus Mountains*

## Central Caucasus series

The dates below are part of the complex study of glaciation and moraine accumulation dynamics related to modern glacial processes (Serebryannyi *et al.* 1984). Samples subm. by L. R. Serebryannyi, Inst. Geography, USSR.

*Salkanalla.* The Salkanalla bog is one of the small spring-type *Carex* peat bogs in the Kriyut. The 80–120 m bog lies W-E, 2150 m asl and terminates in the E by a pronounced rock threshold, below which a tributary of Kshlyksu River begins. The latter flows into the Cherek Bezengi River near Sovetski settlement.

**TA-840. Salkanalla** **160 ± 50**

*Carex* peat from 27–30 cm depth.

**TA-841. Salkanalla** **840 ± 60**

Sedge peat from 48–50 cm depth.

**TA-842. Salkanalla** **1840 ± 70**

Sedge peat from 72–75 cm depth.

**TA-843. Salkanalla** **1930 ± 70**

*Carex* peat from 100–103 cm depth.

**TA-844. Salkanalla** **3500 ± 70**

Sedge peat from 136–139 cm depth.

**TA-845. Salkanalla** **3890 ± 70**

*Carex* peat from 175–178 cm depth.

### Bezengi series

Stratigraphic sections were taken from the Cherek River Valley, 7.5 and 5.5 km from Bezengi Glacier.

**TA-865. Bezengi 1** **3350 ± 70**

Peat with considerable admixture of sand from 55–58 cm depth.

**TA-866. Bezengi 1** **4250 ± 80**

Peat with considerable admixture of sand from depth 65–70 cm depth.

**TA-867. Bezengi 2** **650 ± 80**

Loam formed into humus from depth 60–65 cm depth.

### Karasu series

Karasu bog is 500–300 m, 2000 m asl, in a large glacial depression of Karasu River Valley, 3 km SE of confluence of Dyhsu and Karasu Rivers, giving rise to Cherek Balkarsky River.

**TA-1047. Karasu 1** **1720 ± 80**

*Carex* peat with mineral admixtures from 145–150 cm depth.

**TA-1048. Karasu 1** **2390 ± 80**

*Carex* peat with mineral admixtures from 190–195 cm depth.

### Kurnoyat series

Kurnoyat is small bog in Kryut in Psygansu River Valley, 1900 m asl. Peat is *ca.* 7 m thick, overlain by peat sapropel.

**TA-1112. Kurnoyat** **450 ± 60**

Fen peat with mineral admixtures from 95–100 cm depth.

**TA-1109. Kurnoyat** **3180 ± 60**

Peat sapropel with mineral admixtures from 565–570 cm depth.

### Haldeschal series

Haldeschal is a small *Carex* peat bog in Haldeschal River Valley, 2300 m asl, 2.5 km from glacier.

**TA-1230. Haldeschal** **1020 ± 70**

Bryales-sedge peat with mineral admixtures from 70–73 cm depth.

**TA-1231. Haldeschal** **1380 ± 70**

*Carex* peat with mineral admixtures from 103–106 cm depth.

**TA-1232. Haldeschal** **1550 ± 70**

*Carex* peat with mineral admixtures from 130–133 cm depth.

**TA-1233. Haldeschal** **3360 ± 90**

*Scheuchzeria* peat on peat sapropel with mineral admixtures from 145–150 cm depth.

### Sakeni series

Sakeni River Valley is one of main tributaries of Kodari River in NE Abkhazia.

**TA-1227. Sakeni 2** **1130 ± 70**

Forest peat with mineral admixtures from 10–15 cm depth.

**TA-1228. Sakeni 2** **1220 ± 70**

Forest peat with mineral admixtures from 20–25 cm depth.

**TA-1229. Sakeni 2** **1050 ± 70**

Wood remains from 45–55 cm depth.

### Low Sakeni series

**TA-1234. Sakeni "L"** **440 ± 50**

Fen-type *Carex* peat with mineral admixtures from 40–42 cm depth.

**TA-1235. Sakeni "L"** **1000 ± 60**

Fen-type *Carex* peat with mineral admixtures from 80–82 cm depth.

**TA-1236. Sakeni "L"** **1260 ± 60**

Fen-type *Carex* peat with mineral admixtures from 108–110 cm depth.

**TA-1237. Sakeni "L"** **1320 ± 60**

Fen-type *Carex* peat with mineral admixtures from 148–152 cm depth.

**TA-1238. Sakeni "L"** **2250 ± 60**

*Equisetum* peat with mineral admixtures and woody branches from 207–210 cm depth.

**TA-1279. Sakeni "L"** **2430 ± 70**

Wood remains from 210 cm depth.

**TA-1239. Sakeni "L"** **2270 ± 60**

Fen peat from 240–245 cm depth.

**TA-1278. Sakeni "L"** **3080 ± 70**

Peat layer in sapropel with mineral admixture from 248–252 cm depth.

**TA-1280. Sakeni "L"** **2740 ± 90**

Peat layer in sapropel with mineral admixture from 335–345 cm depth.

*Aktoprak, Georgia*

Aktoprak is archaeological site, 1360 m asl, 1.5 km from Kektash River confluence with Chegem River.

**TA-1056. Aktoprak** **2100 ± 60**

Charcoal layer in carbonated loam deposits from 200–205 cm depth.

*Spitsbergen, Norway*

### Semmeldalen series

Semmeldalen peat moor in Semmeldalen Valley, Nordenskjöld Land, 61 km from Semmeldals-elva River confluence with Rein-o River, on 5 m terrace (25 m asl), is intensively undermined by river. Terrace is covered with peat overlying thick subterranean ice 300 m along Semmeldals-elva River. the terrace rests against gently sloping proximal slope of ridge of probably glacial origin (Serebryannyi *et al.* 1984). Samples subm. by L. R. Serebryannyi. Lithium carbide was synthesized with $CO_2$ because of abundant mineral admixtures in samples.

**TA-1509. Semmeldalen** **1830 ± 300**

Peat with mineral admixtures from 45 cm depth.

**TA-1510. Semmeldalen** **2890 ± 300**

Peat with mineral admixtures from 58–63 cm depth.

**TA-1511. Semmeldalen** **2980 ± 400**

Peat with mineral admixtures from 73–78 cm depth.

**TA-1513. Semmeldalen** **3250 ± 300**

Peat with mineral admixtures from 90 cm depth.

**TA-1512. Semmeldalen** **2210 ± 200**

Peat with mineral admixtures from 110–115 cm depth.

**TA-1557. Semmeldalen** **4440 ± 150**

Peat with mineral admixtures from 155–165 cm depth.

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# UNIVERSITY OF BARCELONA RADIOCARBON DATES I

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## INTRODUCTION

The Radiocarbon Laboratory at the University of Barcelona began its serial measurements in 1985. The following list contains dates obtained between 1985 and 1987. Both archaeological and geological samples were dated.

The measurement technique we use is liquid scintillation counting of benzene. A previous paper (Mestres, García & Rauret 1991) describes sample pretreatment, synthesis and counting protocols and equipment.

Dates are expressed in radiocarbon years relative to A.D. 1950 based on 5568 years, the Libby half-life for $^{14}$C. Those dated since September 1987 are corrected for isotopic fractionation ($\delta^{13}$C values are given relative to PDB). The modern reference standard is the new NBS oxalic acid (factor 0.7459) corrected by isotopic fractionation. No corrections were made for $^{14}$C reservoir effect. The radiocarbon dates are not dendrochronologically calibrated.

Errors quoted are one standard deviation and include the counting errors for the sample, the modern standard and background, and counting efficiency. More details on calculations are in Mestres, García and Rauret (1991). Descriptions, comments and references to publications are based on information supplied by collectors and submitters.

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## ARCHAEOLOGICAL SAMPLES

### *Spain*

### Cancho Roano series

Samples from Cancho Roano, Zalamea de la Serena, Badajoz (38°31'N, 5°40'W). Most samples are charcoal from different places of protohistoric funeral construction (6th, 5th century) (Maluquer 1983). Coll. and subm. by J. Maluquer, Dept. Prehistory and Archaeology, Univ. Barcelona.

**UBAR-14. IAB-60** **2440 ± 90**

Charcoal from Sector 3, 2.37 m depth.

**UBAR-22. IAB-54** **2520 ± 120**

Charcoal from Sector 3, 2.37 m depth.

**UBAR-23. IAB-61** **2500 ± 100**

Charcoal from Sector 3, 2.37 m depth.

**UBAR-29. IAB-55** **2470 ± 100**

Charcoal from Sector 3.

**UBAR-37. IAB-57** **2330 ± 90**

Wheat seed carbonized from Sector 5, 1.34 m depth.

**UBAR-19. IAB-68** **2720 ± 100**

Charcoal from Room 5, 2 m depth.

**UBAR-8. IAB-64** **2620 ± 100**

Charcoal from Room 6, 2.20 m depth.

**UBAR-17. IAB-66** **2450 ± 60**

Charcoal from Room 8.

**UBAR-27. IAB-65** **2360 ± 100**

Charcoal from Room 8.

**UBAR-18. IAB-63** **2710 ± 100**

Charcoal from E 8.

**UBAR-9. IAB-69** **2650 ± 70**

Charcoal from eastern court on flagstone pavement, 3.70 m depth.

*General Comment*: dates agree with expected ages.

### Cerrillo Blanco - Porcuna series

Samples of charcoal from Cerrillo Blanco, Porcuna, Córdoba (37°52′N, 4°11′W). Samples are related to Greek pottery of 4th century B.C. Coll. and subm. by J. Maluquer.

**UBAR-24. IAB-58** **2410 ± 90**

**UBAR-25. IAB-59** **2360 ± 100**

*General Comment*: dates agree with expected ages.

### Pixarelles Cave series

Charcoal from Pixarelles Cave, Tavertet (42°1′N, 2°22′E). Samples are from different layers of two areas. Pixarelles Cave was used from Late Neolithic to Bronze Age (Rauret 1987). Series was dated to establish stratigraphic $^{14}$C chronology and to relate it to cultural chronology (Rauret, Mestres & García 1989). Coll. 1984 and subm. 1985 by A. M. Rauret, Inst. Archaeology, Univ Barcelona.

**UBAR-10. IAB-101/104/105/108** **2870 ± 100**

Square A, Layer VIII.

**UBAR-11. IAB-106** **3150 ± 120**

Square A, Layer XIII.

**UBAR-36. IAB-110** **2980 ± 130**

Square B, Layer XIII.

**UBAR-12. IAB-109** **3500 ± 230**

Square A, Layer XVII.

**UBAR-13. IAB-100/103** **3940 ± 220**

Square W, Layer IV.

*General Comment*: dates agree with stratigraphic succession. Lack of resolution of dates from Late and Middle Bronze Age is settled by cultural affiliation.

### Bòbila Madurell series

Charcoal from Bòbila Madurell, St. Quirze, Barcelona (41°32′N, 2°05′E). Bóbila Madurell is extensive archaeologic site with approximately two different areas: 1) "Sepulcros de fosa" belongs to Middle Neolithic and Chalcolithic periods; 2) belongs to Early and Middle Bronze and Iron Age periods. In both sectors, there are some remains of Veraza Neolithic and some silo structures (Llongueras, Petit & Marcet 1982; Llongueras, Marcet & Petit 1986; Martín 1985; Martín *et al.* 1988). Three samples, UBAR-4, -5 and -6, were coll. before 1985 and subm. 1985 by M. Llongueras; the others were coll. and subm. 1987 by A. Martín, Servei Arqueol., Generalitat Catalunya.

**UBAR-83. BM/B-4** **3620 ± 80**

Sector B, Structure B-4, Level 6.

**UBAR-84. BM/B-12** **5010 ± 80**

Sector B, Pit-silo B-12.

**UBAR-4. FOC-1** **3480 ± 80**

Fire structure or possible silo in Middle Neolithic and Chalcolithic sector.

**UBAR-5. FOC-2** **4940 ± 250**

Same as above.

**UBAR-6. HABITAT-1** **4970 ± 80**

Structure, possible habitat or pit.

**UBAR-85. BM/D7b** **2410 ± 70**

Sector D, pit-silo or possible Oven D-7b, Level IV.

**UBAR-86. BM/D-26** **2440 ± 60**

Sector D, pit-silo D-26, Level 1.

**UBAR-87. BM/D-38** **3350 ± 90**

Sector D, pit-silo D-38, 50 cm depth.

**UBAR-88. BM/D-40** **2700 ± 120**

Sector D, pit D-40, 30–50 cm depth.

*General Comment* (AM): dates agree with materials that appeared in fill of silos. Only the date of UBAR-88, does not agree with expected age (2600–1900 B.C.); structure D-40 was the worst preserved.

### Can Tintoré series

Charcoal from Can Tintoré, Gavà, Barcelona (41°18′N, 2°0′E). This archaeologic site is underground mine (siliceous and phosphate-baricite) whose galleries were re-used as sepulchral site (Level IV). Occupation begins at Early Neolithic and ends at Late Neolithic with its main moment at Middle Neolithic (Villalba *et al.* 1986; Villalba, Blasco & Edo 1989). UBAR-30, coll. before 1983; UBAR-46 to -49 coll. 1983; UBAR-41, 42 coll. 1986; subm. 1986 by J. Villalba, Mus. Gavà.

**UBAR-30. (1) 7CT-28A-h-IV** **4710 ± 130**

Mine 28, Gallery A, Level h, Layer IV. Previously dated as I-13099: 4820 ± 100 B.P.

**UBAR-47. 2/7CT-28A-i-IV** **4610 ± 90**

Mine 28, Gallery A, Level i, Layer IV.

**UBAR-49. 4/7 CT-28A-i-V** **4740 ± 90**

Mine 28, Gallery A, Level i, Layer V. No sepulchral level.

**UBAR-46. 3/7 CT-28A-k-IV** **4380 ± 80**

Mine 28, Gallery A, Level k, Layer IV.

**UBAR-48. 5/8 CT-28C-1-I** **4690 ± 100**

Mine 28, Gallery C, Level 1, Layer I.

**UBAR-42. 86/CT-41-Ib-22** **4820 ± 100**

Mine 41.

**UBAR-41. 86/CT-49** **4970 ± 110**

Mine 49. No sepulchral level.

*General comment* (JV): dates confirm that sepulchral level was used continuously for short period of time corresponding to primary and successive burials. Date of UBAR-46 is younger than expected.

### Font de la Vena series

Charcoal from Font de la Vena, Tavertet, Barcelona (42°01′N, 2°26′E). Site is dolmen-tumulus with some Middle Neolithic materials (Montboló pottery). Coll. and subm. 1986 by J. Castells, Servei Arqueol., Generalitat Catalunya.

**UBAR-61. Font de la Vena-4** **6190 ± 100**

Near dolmen at same depth as Montboló pottery, 63 cm depth.

**UBAR-60. Font de la Vena-3** **5780 ± 290**

Near dolmen below Montboló pottery at 84 cm depth.

*General comment*: dates are older than expected by archaeologists, in both cases, 3500–3000 B.C.

### Cova-120 series

Samples from Cova-120, Sales de Llierca, Girona (42°17′N, 6°18′E). Cave was occupied in Middle Paleolithic, in Neolithic with silo structures, in Chalcolithic and in Bronze Age with burials, and later (Cent-Vint Group 1987). Previous dates are: Level I – UGRA-106: 440 ± 160 B.P.; UGRA-107: 3190 ± 140 B.P. (C. González, P. Sánchez & M. Domingo 1985); Level II – Gif-6925: 4240 ± 70 B.P. Coll. 1984 and subm. 1986 by G. Alcalde, Mus. Comarcal Garrotxa.

**UBAR-34. C-120-B-15-10** **300 ± 70**

Wood from Level I, previously dated as UGRA-106.

*Comment* (GA): date is much younger than expected, no archaeologic reasons are found.

**UBAR-31. C-120-F-16** **8550 ± 150**

Charcoal from 7 m$^2$ in Level III.

*Comment* (GA): date is older than expected, probably due to contamination from mixing of samples in Paleolithic level.

**UBAR-90. Aldovesta Carbó de Pi** **2360 ± 60**

Charcoal from Aldovesta, Benifallet, Tarragona (40°59′N, 0°31′E). Sample is related with Iron Age pottery with Phoenician amphora. Coll. 1986 and subm. 1987 by J. Sanmartí, Dept. Prehistory and Archaeology, Univ. Barcelona.

*Comment*: date agrees with expected age (4th century B.C.).

**UBAR-89. CBA-1+2** **3960 ± 60**

Charcoal from Brics d'Ardèvol, Pinós de Solsonés, Lleida (42°6′N, 5°12′E). Site is Chalcolithic open-air settlement. Sample came from ten fire structures. Coll. and subm. 1987 by J Castany.

*Comment* (JC): date agrees with age expected from Chalcolithic objects.

**UBAR-57. Cova del Senglar** **4100 ± 80**

Charcoal from Cova del Senglar, Albanyà, Girona (42°9′N, 2°38′E). Site is cave with Late and Early Bronze and Early Neolithic occupations. Sample is from Neolithic level (sepulchral), 50–60 cm depth. Coll. and subm. 1986 by J. Tarrús and A. Bosch, Mus. Arqueol. Comarcal Banyoles.

*Comment* (JT): date is younger than expected (3900–3400 B.C.); pottery of this level belongs to Postcardial-Montboló complex of northeastern Catalonia.

**5270 ± 70**
**UBAR-101. Cova del Pasteral Z-III** $\delta^{13}C = -19.9‰$

Bones from Cova del Pasteral, La Cellera de Ter, Girona (41°58′N, 2°36′E). Site is Early Neolithic funeral cave (Bosch 1985). Sample comes from Zone-III. Coll. 1982 and subm. 1987 by A. Bosch and J. Tarrús.

*Comment* (JT): date is younger than expected (4200–3900 B.C.); cave pottery belongs to Epicardial complex of northeastern Catalonia.

**5830 ± 100**
**UBAR-109. Cova de l'Avellaner Z-III** $\delta^{13}C = -20.2‰$

Bones from Cova de l'Avellaner, Les Planes d'Hòstoles, Girona (42°04′N, 2°32′E). Site is cave with three sepulchral areas (Bosch & Tarrús 1987). Sample comes from Zone III. Coll. and subm. 1986 by A. Bosch and J. Tarrús.

*Comment* (JT): date agrees with expected age (3900–3600 B.C.). Pottery of this sepulchral cave belongs to Postcardial-Montboló complex of northeastern Catalonia.

**5100 ± 110**
**UBAR-100. Els Garrofers** $\delta^{13}C = -18.6‰$

Human bones from Els Garrofers del Torrent de Santa Maria, Vilanova i la Geltrú, Barcelona (42°12′N, 1°41′E). Site is open-air sepulchral level of Middle Neolithic "sepulcros de fosa." Sample comes from 5–10 cm below present surface (Martín & Miret, in press). Coll. 1985 and subm. 1987 by A. Martín.

*Comment*: date agrees with expected age.

**UBAR-63. Cova dels Lladres-I** **5330 ± 90**

Wood from Cova dels Lladres, Vacarisses, Barcelona (41°36′N, 1°55′E). Site is Early Neolithic sepulchral cave. Sample comes from near Burial 1 (Ten 1989). Coll. before 1981 and subm. 1986 by R. Ten, Servei Arqueol., Generalitat Catalunya. Only acid pretreatment was given.

*Comment*: date agrees with expected age.

**UBAR-72. Font Voltada-Foc 3** **10,920 ± 240**

Charcoal from Cova de la Font Voltada, Montbrió de la Marca, Tarragona (41°28′N, 1°18′E). Site is small Late Epigravettian cave. Sample comes from 45–80 cm below datum. Coll. 1983/

85 and 1987 subm. by A. Mir, Mus. Arqueol. Salvador Vilaseca, Reus.

*Comment*: date agrees with expected age.

## GEOLOGICAL SAMPLES

*Spain*

### Llobregós River terrace series

Samples from Llobregós River, Torà, Lleida (41°48′N, 1°25′E). Samples were taken from first terrace level (+7 m) above present alluvial plane of Llobregós River. These alluvial deposits are sandy and silty with many gypsum grains. Coll. 1987 by J. Escuer and subm. 1987 by J. Calvet, Dept. Dynamic Geol., Univ. Barcelona.

**UBAR-64. F-1'** **4550 ± 80**

Sample 2 m below top of terrace.

**UBAR-65. F-1** **4800 ± 140**

Sample 5 m below top.

*General Comment* (JC): dates are in Holocene period as expected.

**UBAR-96. Monistrol A-1** **240 ± 50**
$\delta^{13}C = -26.6‰$

Bituminous slime sediments from Monistrol d'Anoia, Barcelona (41°27′N, 1°47′E). Sample coll. from upper level of Quaternary terrace 15 m above present level of Anoia River. Continental Upper Miocene deposits are below Quaternary sediments (Gallart 1981). Coll. and subm. 1987 by F. Gallart, Inst. J. Almera, CSIC, Barcelona.

*Comment*: date is much younger than expected, perhaps due to presence of bomb $^{14}C$ in sample.

**UBAR-58. Mostra 4/Core E** **1510 ± 80**

Slime sediments from Estany d'Ullastret, Pla. St. Andreu, Girona (42°00′N, 3°05′E). Sample coll. when drilling Quaternary paleolake sediments, at 5.60–5.70 m depth from present surface. These sediments overlay Eocene materials (Santanach, Sanz de Galdeano & Busquets 1980). Coll. 1984 and subm. 1986 by A. Esteban, Dept. Prehistory and Archaeology, Univ. Barcelona.

*Comment*: date agrees with age expected by submitter.

### Delta del Llobregat series

Samples from delta of Llobregat River, Barcelona (41°19′N, 2°07′E). From the present, continental surface sediment sequence in delta is: fluvial sediments, marine silty and clayed (Flandriense, Holocene) and fluvial sediments at base of Holocene and Pliocene deposits (Marqués 1984). Samples coll. 1985 by drilling and subm. 1986 by M. Manzano, Dept. Stratigraphy, Univ. Barcelona.

**UBAR-33. Delta Llobregat 7-34** **2300 ± 1200**

Peat from marine clays (Flandriense).

**UBAR-32. Delta Llobregat 7'-65** **> 28,100**

Marine bivalve shell from pre-Holocene deposits.

*General Comment* (MM): as expected, using geochronologic criterion, base of Flandriense transgression is > 12,000 B.P.; top is *ca.* 2000 B.P.

### La Marjal de Pego-Oliva series

Peat from beach-marsh system in Pego-Oliva, La Safor, València. Samples obtained by drilling in different places within beach marsh (Pérez, Sanjaume & Fumanal 1985; Fumanal, Sanjaume & Pérez-Cueva 1985). Coll. 1986 and subm. 1987 by V. Rosselló, Dept. Geog., Univ. València.

**UBAR-77. Pego 1/17** **10,120 ± 460**

Drilling 1 (38°53′N, 0°02′W), > 20 m depth.

**UBAR-78. Pego 3/16** **8300 ± 170**

Drilling 3 (38°53′N, 0°03′W), 16.5–15.8 m depth.

**UBAR-43. Pego 5/19** **7120 ± 90**

Drilling 5 (38°51′N, 0°03′W), *ca.* 13 m depth.

**UBAR-79. Pego 6/5** **2400 ± 60**

Drilling 6 (38°52′N, 0°03′W), 1.8–2.0 m depth.

**UBAR-80. Pego 6/7** **3250 ± 100**

Drilling 6 (38°52′N, 0°03′W), 2.2–2.4 m depth.

**UBAR-81. Pego 6/11** **3540 ± 80**

Drilling 6 (38°52′N, 0°03′W), 3.0–3.2 m depth.

**UBAR-82. Pego 6/12** **5330 ± 90**

Drilling 6 (38°52′N, 0°03′W), 3.2–3.4 m depth.

**UBAR-44. Pego 7/16** **7790 ± 110**

Drilling 7 (38°52′N, 0°04′W), *ca.* 12 m depth.

**UBAR-45. Pego 7/32** **> 28,240**

Drilling 7 (38°52′N, 0°04′W), *ca.* 19 m depth.

*General Comment* (VR): dates of beach-marsh system of Pego-Oliva are part of study of Quaternary littoral evolution of Mediterranean Sea Valencia coast. Dates show two general sea transgressions, one at Upper Pleistocene and the other at Holocene.

## Catalonia coast series

Samples from Catalonia continental shelf, Mediterranean Sea erosion. Samples obtained from outcropping of Quaternary units (R1 1989; R2 1986). Coll. 1984 M. Farrán and subm. 1987 by A. Maldonado, Inst. J. Almera, CSIC. Outer portion of shells was removed before dating (Mestres, García & Rauret 1991).

**UBAR-68. GC-84-6 TR-665** **2260 ± 80**

Marine bivalve shell from Begur, Girona (41°54'N, 3°21'E), 20 cm depth.

**UBAR-67. GC-84-6 TR-645** **> 35,200**

Marine bivalve shell from Palamós, Girona (41°51'N, 3°14'E), 28 cm depth.

**UBAR-69. GC-84-6 TR-619** **34,100 ± 2200**

Marine bivalve shell from Palamós, Girona (41°43'N, 3°6'E), 25 cm depth.

**UBAR-70. GC-84-I TR-233** **13,100 ± 250**

Marine shell from Tossa de Mar, Girona (41°33'N, 2°47'E), 18 cm depth.

**UBAR-71. TC-3 (15 cm)** **1310 ± 60**

Marine shell from Besós River, Barcelona (41°23'N, 2°16'W), 15 cm depth.

**UBAR-66. CL-83-I K-94** **10,320 ± 170**

Peat from L'Ampolla - Hospitalet de l'Infant, Tarragona (40°54'N, 0°51'W), 75–80 cm depth.

*General Comment* (MF): results obtained for carbonates do not agree with expected ages. This must be due to recrystallization or transport of basal sediments by trawling. Results of sediment samples agree with expected ages.

## Balearic Islands series

Samples from Balearic Islands continental shelf (water depth < 200 m), obtained by drilling at different depths of Holocene level (Alonso *et al.* 1988). Coll. 1985 and subm. 1986 by B. Alonso and J. Guillem, Dept. Stratigraphy, Univ. Barcelona, except UBAR-26, coll. and subm. by I. Zamarreño, Inst. J. Almera, CSIC, Barcelona.

**UBAR-54. 85-CA-56 (124)** **9910 ± 140**

Carbonate rock accreted on algal core from Alcudia Bay, (39°56'N, 3°15'E), at 124 cm depth from bottom of sea.

**UBAR-55. 85-CA-52 (402-410)** **8570 ± 110**

Carbonate rock accreted on algal core from Alcudia Bay (39°53'N, 3°37'E), at 402–410 cm depth from bottom of sea.

**UBAR-53. 85-CA-51** **8670 ± 90**

Carbonate rock accreted on algal core from Alcudia Bay (39°51′N, 3°19′E), at 4 cm depth from bottom of sea.

**UBAR-56. 85-CA-56 (29-37)** **13,100 ± 200**

Carbonate rock accreted on algal core from Alcudia Bay (39°56′N, 3°15′E), at 29–37 cm depth from bottom of sea.

**UBAR-20. 85-CA-60 (160-190) A** **11,840 ± 210**

Marine gastropod shell covered by contemporary organisms from south Majorca (39°59′N, 3°35′E), at 160–190 cm depth from bottom of sea.

**UBAR-21. 85-CA-60 (160-190) B** **13,500 ± 320**

Marine bivalve shells from south Majorca (39°59′N, 3°35′E), at 160–190 cm depth from bottom of sea.

**UBAR-52. 85-CA-9** **9610 ± 100**

Recrystallized shell from south Majorca (39°16′N, 2°51′E), at 125 cm depth from bottom of sea.

**UBAR-62. 85-CA-47** **MODERN**

Marine bivalve shells from the channel between Majorca and Minorca (39°54′N, 3°39′E), at 5 cm depth from bottom of sea.

**UBAR-26. 35430** **810 ± 60**

Coral from platform between Majorca and Ibiza (38°40′N, 2°24′E). Dated by U/Th at 13,220 +450/-325 (J. Bischoff, pers. commun. 1987)

*General Comment* (JG): dates beginning of holocene transgression. Inversion between dates UBAR-56 and -54 could be attributed to nature of sample material, mixing and/or diagenesis.

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# UNIVERSITY OF GRANADA RADIOCARBON DATES V

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## INTRODUCTION

This paper includes some determinations of archaeological, art and palaeobotanical samples from Spain and Portugal, obtained at the University of Granada Radiocarbon Dating Laboratory, mostly from 1986 to 1988. Pretreatment of charcoal and wood samples is a standard acid-basic procedure using 8% HCl and 2% NaOH at boiling temperature. The collagen of bone samples is obtained by the Longin (1971) method.

The method of dating is benzene synthesis and liquid scintillation counting as previously reported (González-Gómez, López-González & Domingo-García 1982; González-Gómez, Sánchez-Sánchez and Domingo-García 1985; González-Gómez, Sánchez-Sánchez and Villafranca-Sánchez 1986, 1987). $^{14}$C activity was measured in a Packard Tri-Carb Mod 4640 liquid scintillation spectrometer, using 20 ml low $^{40}$K counting vials with 5 ml benzene and 10 ml PPO-toluene as scintillator with a background of *ca.* 9 cpm. Efficiency was approximately 70% using the part of spectrum above the end point of tritium.

Dates reported here are based on 0.95 of the activity of NBS oxalic acid modern standard and the Libby $^{14}$C half-life of 5568 years. Samples were measured for 100 minutes repeating 30–40 times, as well as background and standard vials. The standard deviation quoted includes only 1 $\sigma$ of the counting statistics of background, sample and modern standard counts. Calculations and data are processed by a PC computer, using extended programs made by González-Gómez (Computer-extended programs for radiocarbon dating laboratories, ms. in preparation). Calibrated ages for a 2 $\sigma$ interval, are obtained by the method of Pearson *et al.* (1986), running the computer programs CALIB (Stuiver & Reimer 1986) and CALI (González-Gómez, CALI, a computer program for calibration of radiocarbon dates, ms. in preparation) using the bidecadal curve for atmospheric origin samples. $\delta^{13}$C corrections are based on data reported by Stuiver and Polach (1977).

Sample descriptions are based on information supplied by those who submitted samples.

## ACKNOWLEDGMENTS

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## ARCHAEOLOGICAL SAMPLES

### *Spain*

### El Acequión series

Samples from El Acequión (39°01'N, 2°01'W), Albacete. Coll. 1985–1986 and subm. 1987 by M. D. Fernández-Posse and C. Martín-Morales, Ministry of Cultura, Madrid, to date Bronze Age in E La Mancha.

**UGRA-265. AC-786-24a** **3770 ± 80**

Charcoal from depth 1.86 m; cal. B.C. 2460–1970.

**UGRA-266. AC-786-24b** **3680 ± 80**

Charcoal from depth 1.86 m; cal. B.C. 2320–1880.

**UGRA-271. AC-786-24c** **3730 ± 100**

Charcoal from depth 1.86 m; cal. B.C. 2460–1890.

**UGRA-302. AC-285-40** **5010 ± 150**

Charcoal from depth 1.42 m; cal. B.C. 4224–3386.

**UGRA-304. AC-286-71** **3790 ± 120**

Charcoal from depth 2.52 m; cal. B.C. 2577–1890.

**UGRA-307. AC-285-4** **3020 ± 90**

Charcoal from depth 0.80 m; cal. B.C. 1509–1000.

**UGRA-309. AC-785-8** **2990 ± 90**

Charcoal from depth 0.80 m; cal. B.C. 1440–942.

*General Comment:* dates agree with archaeol. expectation, in study of last stage of occupation of site.

### Cabezo del Cuervo series

Samples from Cabezo del Cuervo (41°03′N, 0°08′W), Alcañiz, Teruel prov. Coll. 1982 by J. Vicente-Redón and subm. 1984 by P. Atrián-Jordán, Mus. Archaeol. Teruel, to date different cultural levels in middle valley of Ebro River.

**UGRA-215. No. 23** **3410 ± 90**

Wood from depth 1.20 m; cal. B.C. 1950–1520.

**UGRA-216. No. 37** **3450 ± 90**

Wood from depth 1.50 m; cal. B.C. 2028–1530.

**UGRA-228. No. 15** **3320 ± 90**

Wood from depth 0.70 m; cal. B.C. 1878–1420.

**UGRA-229. No. 53** **3420 ± 90**

Wood from depth 2.37 m; cal. B.C. 1960–1520.

**UGRA-230. No. 47** **3220 ± 90**

Wood from depth 1.75 m; cal. B.C. 1734–1310.

**UGRA-239. No. 6** **3340 ± 90**

Wood from depth 0.63 m; cal. B.C. 1880–1430.

**UGRA-240. No. 31** **3340 ± 130**

Wood from depth 1.35 m; cal. B.C. 1960–1328.

**UGRA-269. No. 44** **3230 ± 80**

Wood from depth 1.72 m; cal. B.C. 1731–1324.

*General Comment:* dates agree with archaeol. expectation.

### El Castillo de Burgos series

Samples from El Castillo de Burgos (Burgos Castle) (42°20′N, 3°43′W). Coll. 1985 by J. M. Martínez-González and subm. 1985 by J. L. de Uribarri-Angulo to date cultural stages at end of Bronze Age and first Iron Age.

**UGRA-226. No. 9 Nivel XII** **2900 ± 100**

Charcoal from depth 2.08 m; cal. B.C. 1410–840.

**UGRA-227. SII-NI-M1** **2710 ± 80**

Seeds from depth 1.52 m; cal. B.C. 1040–790.

*General Comment:* expected age was *ca.* 2720 ± 250 B.P.

### Cerrillo Blanco

Charcoal from Cerrillo Blanco (37°52′ N, 4°11′W), Porcuna, Jaén prov. Interlaboratory check sample subm. 1988 by Barcelona Radiocarbon Dating Laboratory.

**UGRA-280. MIP IAB-58/59** **2530 ± 80**

*Comment:* UBAR date was 2650 ± 90; cal. B.C. 830–400.

### Cerro de la Mora

Sample from Cerro de la Mora (37°14′N, 3°59′W), Moraleda de Zafayona, Granada prov. Charcoal from depth 4 m coll. and subm. by J. Carrasco-Rús to date end of Bronze Age in an Argaric-type fortification. Other samples from Cerro de la Mora were dated previously by González-Gómez, Sánchez-Sánchez and Domingo-García (1985: 611), González-Gómez, Sánchez-Sánchez and Villafranca-Sánchez (1986: 1201, 1987: 384).

**UGRA-283. Cm/87/Fondo** **3030 ± 80**

*Comment:* date agrees with expected age; cal. B.C. 1495–1030.

### Dolmen de Azután

Bones from Dolmen de Azután (39°45′N, 5°10′W), Azután, Puente del Arzobispo, Toledo prov. Sample from 1.70 m depth coll. 1983 and subm. 1985 by P. Bueno-Ramírez, Dept. Prehist., Univ. Alcalá de Henares, Madrid prov., to date megalithic chronology in Meseta.

**UGRA-288. AZUTAN** **5060 ± 90**

*Comment:* expected age was *ca.* 4800 ± 150 B.P.; cal. B.C. 4038–3690.

### Ermita de San Fructuoso

Sample from Ermita de San Fructuoso (43°14′N, 4°17′W), La Miña, Ruente, Cantabria. Charcoal from 0.70 m depth coll. 1985 by E. van den Eynde Ceruti and subm. 1985 by M. A. García-Guinea, Mus. Reg. Prehist. & Archaeol. Santander. This date is important for correct interpretation of site.

**UGRA-270. C1T 2** **1090 ± 80**

*Comment:* expected age was *ca.* 1010 ± 350 B.P.; cal. A.D. 770–1113.

### Les Grioteres

Sample from Les Grioteres (41°58′N, 2°23′E), Vilanova de Sau, Barcelona prov. Charcoal from 1.70 m depth coll. 1985 and subm. 1986 by J. Castany-Llussa, Inst. Prehist. & Archaeol. Univ. Barcelona, to date first human occupation of site in Neolithic period.

**UGRA-274. G-N 7** **5280 ± 90**

*Comment:* expected age was *ca.* 5210 ± 250 B.P.; cal. B.C. 4340–3825.

### Los Panizales

Sample from Los Panizales (41°02′N, 0°09′W), Alcañiz, Teruel prov. Charcoal from 0.25 m depth coll. and subm. 1987 by J. A. Benavente-Serrano, Taller Arqueol Alcañiz. Sample from inner part of probable tumulus close to surficial lithic bed. Relation between both is doubtful. End of Neolithic period.

**UGRA-299. P-1** **2310 ± 90**

*Comment:* cal. B.C. 763–180.

*Portugal*

### Alto do Castelo

Wood from Alto do Castelo (39°15′N, 8°35′W), Alpiarça, Santarém prov. Sample coll. 1982 by P. Kalb and subm. 1987 as interlaboratory comparison sample by the Lisbon Radiocarbon Dating Laboratory.

**UGRA-281. AC-466** **2020 ± 80**

*Comment:* ICEN-122: 2120 ± 70 B.P.; cal. B.C. 340 – cal. A.D. 130.

### Barrocal. Alto series

Charcoal from Barrocal Alto (41°16′N, 6°33′W), Peredo da Bemposta, Mogadouro, Tras Os Montes prov. Coll. 1984 by M. de Jesus Sanches, A. Barroso, V. Lopes and A. Gomes-Sebre and subm. 1984 by M. de Jesus Sanches, Porto Archaeol. Study Group, to date prehistoric village.

**UGRA-223. 1/BA-84/S-II/T.26-L** **3230 ± 100**

*Comment:* expected age was *ca.* 3200 ± 250 B.P.; cal. B.C. 1740–1310.

**UGRA-272. 2/BA-84/S-II/U.26** **2050 ± 100**

Cal. B.C. 370 – cal. AD 130.

*Comment*: age is younger than expected – 3200 ± 250 B.P.

**UGRA-273. 3/BA-84/S-II/X.22** **6950 ± 90**

Sample from depth 0.65 m; cal. B.C. 6034–5630.

*Comment*: age is older than expected – 3450 ± 300 B.P.

### Castro do Coto da Pena series

Seeds from Castro do Coto da Pena (41°52′N, 8°50′W), Vilarelho, Caminha, Viana do Castelo prov. Samples coll. 1983 and subm. 1984 by A. Coelho Ferreira da Silva, Univ. do Porto, to date last occupation of site at end of Bronze Age.

**UGRA-200. No. 5** **2950 ± 100**

Cal. B.C. 1430–900.

**UGRA-220. No. 2** **2920 ± 110**

Sample from depth 1.80 m; cal. B.C. 1420–840.

*General Comment:* dates agree with archaeol. expectation that confirm age of occupation of bottom stratum of site.

### Mamoa do Monte da Olheira

Charcoal from Mamoa do Monte da Olheira (41°12′N, 8°02′W), Serra da Aboboreira, Baiâo, Dist. do Porto, Douro Litoral prov. Sample from depth 0.53 m, coll. 1981 and subm. 1987 by D. de Jesus da Cruz, to date megalithic necropolis with 40 tombs in region.

**UGRA-287. Amostra no. 1** **5630 ± 90**

*Comment:* expected age was *ca.* 4960 ± 500 B.P.; cal. B.C. 4720–4340.

### Povoado Pre-Historico da Lavra

Samples from Povoado Pre-Historico da Lavra (41°10′N, 8°04′W), Lavra, Marco de Cavaneses, Soalhaês prov. Coll. 1982 and subm. 1984 by M. de Jesus Sanches to date village.

**UGRA-267. 1-LA.82/E.C.3** **5830 ± 90**

Charcoal to date village; cal. B.C. 4936–4490.

**UGRA-268. 2-LA.82/F.4** **7500 ± 100**

Charcoal to date silo or cave; cal. B.C. 6558–6110.

*General Comment:* expected ages were 3700 ± 250 B.P. for both samples.

## ART SAMPLES

*Spain*

**UGRA-67.** **480 ± 90**

Wood from statue of St. Anthony the Abbot; expected age was *ca.* 15th century A.D. Sample subm. by P. Gómez-Acha, Granada.

**UGRA-141.** **290 ± 90**

Wood from rear side of picture on plank; expected age was *ca.* 17th century A.D. Sample subm. 1983 by J. J. Pons-Marco, Castellón de la Plana.

**UGRA-219.** **410 ± 90**

Wood from rear side of St. Andrew picture on plank; expected age was *ca.* 14th century A.D. Sample subm. 1985 by J. L. Vílchez-Quero and J. Torres-Garzón, Granada.

## PALAEOBOTANICAL SAMPLES

*Spain*

### Barrio de San Miguel series

Samples from Cerro de San Miguel (43°21′N, 1°48′W), Anzarán, Irún, Guipúzcoa prov. Coll. and subm. 1987 by J. M. Edeso-Fito and F. M. Ugarte-Elorza, Soc. Ciencias Aranzadi, Mus. S Telmo, San Sebastián, to date Quaternary littoral paleogeographic evolution on coast of Gulf of Vizcaya (Quipuzcoan sector).

**UGRA-294. A3. 0.85m. (C1)** **>45,000**

Charcoal from depth 4.05 m.

**UGRA-301. Ao. 0.30m. (C4)** **38,300 ± 2100**

Charcoal from depth 3.20 m.

### Maxalen Berri

Sample from Maxalen Berri (43°08′N, 1°51′W), Oyarzum, Guipuzcoa prov. Coll. and subm. 1987 by J. M. Edeso-Fito and F. M. Ugarte-Elorza, Soc. Ciencias Aranzadi, Mus. S Telmo, San

Sebastián, to date Quaternary evolution in Oyarzum River valley.

**UGRA-300. OYA-1** **2550 ± 90**

Wood from depth 2.00 m; cal. B.C. 900–400.

### Sopelana

Sample from Sopelana (43°23′N, 3°00′W), Sopela, Vizcaya prov. Coll. and subm. 1987 by F. M. Ugarte-Elorza to date Würm and Holocene evolution of paleolandscape on Vizcaya coast.

**UGRA-293. Sop-1** **41,400 ± 2500**

Wood from depth 3.00 m.

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# LETTERS TO THE EDITOR

June 3, 1991

Dear Friends of Radiocarbon,

I liked every aspect of the recent Tucson meeting except the papers. In general, they were too specific and too heterogeneous. I think that if we are to improve this situation in Scotland, we must first oust the Old Guard and install a program committee made of Young Turks. For this committee, I suggest

John Vogel
Edouard Bard
Bernd Kromer
Ellen Druffel

I would relegate more of the technical papers to posters. I would run more theme sessions launched with an overview paper aimed at bringing up to speed the non-experts who make up the better part of the audience. I would do everything possible to encourage attendance by AMS users interested in $^{10}$Be, $^{26}$Al, $^{36}$Cl, $^{40}$Ca and $^{129}$I. I would lengthen the time slots to 25 minutes (20 for the talk and 5 for discussion). I would solicit interesting papers from people who might otherwise not attend.

Cheers,

W. S. Broecker

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November 13, 1991

Dear Renee:

I would like to add the comments listed below to the discussion concerning the format of future Radiocarbon Conferences.

1. It is reasonable to have a program committee which would help the local committee by suggesting invited speakers and special topics. The local committee must have the final responsibility for organizing the meeting.
2. Any member of the community (however that is defined) should be allowed to give an oral presentation.
3. A speaker should be able to organize his/her work into a 15-minute presentation. Several additional minutes should be allowed for questions. The schedule should not be so tight as to require premature termination of appropriate discussion.
3. I dislike poster sessions with passion! In my opinion, very little information is exchanged at these sessions which could not be exchanged over a short beer. I would do everything possible (including shortening oral presentations and/or having simultaneous sessions) to banish them. Posters remind me of my children's science fair projects.

5. Perhaps the topic is already covered in (1) above, but some carefully selected invited papers are certainly desirable.
6. I agree completely with the notion that people working with the long-lived cosmogenic isotopes should be encouraged to participate in the Radiocarbon Conferences. However, as has been noted, radiocarbon is the "mother" of such isotopes, and will continue to dominate the conferences.
7. If you are collecting names of "Young Turks," I would urge that you include Tim Jull on the list.

Best regards,

Doug Donahue

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## SHOULD THE "PRESENT" BE DATED?

*E. G. NISBET*

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The terminology, "B.P.," is accepted worldwide by the Earth Science community. It has a long and respected history, originating in legend as "Bill's Practice." However, those teaching geology to students in the 1990s have some problems in explaining that the present is A.D. 1950. To students who do not remember the moon landings for the excellent reason that they were unborn, it is difficult to grasp that the "present" is now so long ago that it is out of analytical error. With the decline in arithmetic skills, many of today's undergraduates find it difficult to subtract 1950 mentally, and do not think of adding 50 and then deducting 2000. For them, it would be simpler to use A.D. 1, which is almost 2000 years ago. Furthermore, non-specialists become disoriented reading scientific papers that jump rapidly between radiocarbon to calendar dates, and from one carbon reservoir to another, all variously called B.P.

To simply change the "present" to A.D. 2000 would irretrievably confuse the literature. One way of resolving the problem is to retain the B.P. usage as in traditional practice, but to introduce an optional new usage based on a datum of A.D. 2000. In this proposal, the letter, "D," for datum, would signify a number related to A.D. 2000. The letter would then be followed in upper case by the dating system (*e.g.*, C for $^{14}$Carbon, BE for $^{10}$Be, *etc.*, CAL for calendar, DEN for tree rings, *etc.*), and if need be, a lower case comment to indicate the reservoir being dated (*e.g.*, ben for benthic). Thus, a carbon date of a benthic organism at 5000 B.P. would become, with rounding, 5050 DCben.

This proposal would make life much easier for the next generation of students, and has the merits that 2000 is a fine round number that will remain the closest millennium for the next five centuries. The other information should make papers easier to read. There should be no confusion if the B.P. notation is also retained, however, for those who prefer it; the two systems are distinctively different.

## REPLY - A VIEW FROM THE OPPOSITE CAMP

Professor Nisbet revisits a thorny problem that has plagued us since the beginning of analytic time. How best to specify our measurements, so they will readily be understood by all? As another pedagogue, I certainly appreciate his comments on the difficulties of explaining to students and non-specialists why we pin radiocarbon time to the strange year, A.D. 1950. However, in my own experience, confusion about radiocarbon ages is not limited to students and non-specialists, but is common amongst primary users as well. Numerous schemes to more closely specify the data and adjustments have been proposed, of which various are still used, causing even further confusion.

I believe that introducing yet another specification method would only add to this confusion, however logical it may seem at the outset. (Further, I have an aversion to making it even easier to subtract calendar years from radiocarbon years.) Stuiver and Polach (1977) have given us a clear definition of "conventional radiocarbon ages." This definition is complicated, but proper use of radiocarbon data requires a basic knowledge of it. The definition is finally becoming widely understood, probably in large part because it leads to the wonderful calibration data that now connects the radiocarbon and calendrical scales. The definition was confirmed and a new notation (*i.e.*, cal. B.P., cal. A.D. and cal. B.C.) for specifying calibrated ages was adopted at the 12th International Radiocarbon Conference (Mook 1986). In my view, changing these definitions now, or adding another new one, will only lead to greater chaos.

That leaves the question of other dating methods, and I'm not convinced that there is a big problem there. Dendrochronologists measure time in dendro-years, which are usually very close to calendar years, and so an A.D./B.C. dendro-scale is appropriate. For most other methods, a discrepancy of only 50 years (in whatever scale) would be a triumph, and so the problem is not nearly so immediate.

Besides, I rather like the year A.D. 1950.

Erle Nelson
Associate Editor

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[RADIOCARBON, VOL. 33, NO. 3, 1991, P. 378]

# RADIOCARBON UPDATES

## *Changes in Groningen*

1. The University of Groningen announces an opening for a full professor of Physics at the Centre for Isotope Research. This concerns the vacancy left by W. G. Mook, who is now director of the Netherlands Institute for Sea Research (NIOZ). The advertisement will appear in *Physics Today*, and can also be obtained from J. van der Plicht in Groningen.

2. By the time you read this, the Groningen people will be busy moving their laboratory to a new location on the Groningen campus, just outside the city. The new address, from December 1991, will be:

Centre for Isotope Research
University of Groningen
Nijenborgh 4
9747 AG Groningen
The Netherlands

Phone numbers and E-mail addresses will remain the same. The new FAX number is:

(31)50-634738

## *Other Changes*

Christine Prior resigned her position as Director of the Radiocarbon Laboratory at the University of Wisconsin–Madison (WIS) as of June 1991. She has subsequently moved to Riverside, and is now the Manager of Erv Taylor's laboratory at the University of California, Riverside (UCR). The new Director of the Wisconsin lab is pending.

## *Workshop Announcement*

A Workshop on "Variation of Cosmogenic Isotopes: Archives and Causes" will be held 10–17 June 1992 in Riga, Latvia. Co-Chairmen for the Workshop are G. E. Kocharov and H. A. Polach. Contact Henry Polach for more details:

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## *Publication*

"Radiocarbon After Four Decades: An Interdisciplinary Perspective" will be published in early 1992 by Springer-Verlag New York and *RADIOCARBON*. This hardcover edition, the symposium volume for the commemorative meeting in Lake Arrowhead, California, 4–8 June 1990, is over 600 pages. It will be offered at a discount to subscribers; it will not be part of the regular *RADIOCARBON* series.

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Since its inception, the basic purpose of *RADIOCARBON* has been the publication of compilations of $^{14}$C dates produced by various laboratories. These lists are extremely useful for the dissemination of basic $^{14}$C information.

In recent years, *RADIOCARBON* has also been publishing technical and interpretative articles on all aspects of $^{14}$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, RADIOCARBON UPDATES 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, include three hard copies, double-spaced. When the final copy is prepared after review, please provide a floppy diskette along with one hard copy. We will accept, in order of preference, WordPerfect 5.1 or 5.0, Microsoft Word, Wordstar or any IBM word-processing software program. ASCII files, MS DOS and CPM formatted diskettes are also acceptable. The diskettes should be either 3½" (720 k or 1.44 megabytes) or 5¼" (360 k or 1.2 megabytes). Radiocarbon papers should follow the recommendations in INSTRUCTIONS TO AUTHORS (R, 1990, v. 32, no. 1, p. 115–118). Offprints are available upon request. Our deadline schedule for submitting manuscripts is:

| *For* | *Date* |
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| Vol. 34, No. 2, 1992 | January 1, 1992 |
| Vol. 34, No. 3, 1992 | Proceedings |
| Vol. 35, No. 1, 1993 | September 1, 1992 |

*Half-life of $^{14}$C.* In accordance with the decision of the Fifth Radiocarbon Dating Conference, Cambridge, England, 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 $^{14}$C measurements are expressed as dates in years B.P., 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 ± 40 yr, (*Nature*, 1962, v. 195, no. 4845, p. 984), is regarded as the best value presently available. Published dates in years B.P. can be converted to this basis by multiplying them by 1.03.

*A.D./B.C. Dates.* In accordance with the decision of the Ninth International Radiocarbon Conference, Los Angeles and San Diego, California, 1976, the designation of A.D./B.C., obtained by subtracting A.D. 1950 from conventional B.P. determinations is discontinued in *RADIOCARBON*. Authors or submitters may include calendar estimates as a comment, and report these estimates as cal. A.D./B.C., citing the specific calibration curve used to obtain the estimate. Calibrated dates will now be reported as "cal. B.P." or "cal. A.D./B.C." according to the consensus of the Twelfth International Radiocarbon Conference, Trondheim, Norway, 1985.

*Measuring of $\delta^{14}$C.* In Volume 3, 1961, we endorsed the notation $\Delta$ (Lamont VIII, 1961) for geochemical measurements of $^{14}$C activity, corrected for isotopic fractionation in samples and in the NBS oxalic-acid standard. The value of $\delta^{14}$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 $\delta^{14}$C as the observed deviation from the standard. At the New Zealand Radiocarbon Dating Conference it was recommended to use $\delta^{14}$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, California, 1976, recommended that the reference standard, 0.95 NBS oxalic acid activity, be normalized to $\delta^{13}C = -19‰$.

In several fields, however, age corrections are not possible. $\delta^{14}$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.

[RADIOCARBON, VOL. 33, NO. 3, 1991]

# A SPECIAL ISSUE IS FORTHCOMING

Dear Colleague,

The paper by Tans, Fung and Takahashi (1990) "Observational Constraints on the Global Atmospheric $CO_2$ Budget" *Science* 247: 1431, raised considerable interest in the possibility that an anthropogenically induced stimulation of carbon storage in soils has occurred. No other reservoir appears to be capable of storing the so-called "missing sink" carbon. If so, then it is essential not only that the cause for this stimulation be found, but also that models be developed which would permit the evolution of its storage capacity to be predicted.

One set of parameters in any such model is the ratio of turnover of carbon in various soil pools. Radiocarbon measurements offer an important constraint in their regard. Of course, even though the wide spectrum of turnover times and the separate contributions of natural and bomb-testing radiocarbon complicate the use of this constraint for the longer time-constant pools, it is all we have. Presumably, this renewed interest in the soil reservoir will lead to a host of new soil measurements. The availability of AMS facilities for radiocarbon measurements makes the task much easier in the sense that a variety of fractions can now be analyzed in any given soil sample.

In expectation of this renaissance, it is appropriate that a summary of existing measurements on contemporary soil organics be made available. Thus, we propose that an issue of *RADIOCARBON* be devoted to a listing of radiocarbon measurements on contemporary soil organics and to commentary on the interpretation of such measurements. To do this, we need the help of all those who have made such measurements. So please copy and fill out the form on the reverse side of this page and send it to Renee.

Cheers,

Wally Broecker
Renee Kra

(over)

Name:

Address:

Tel: Fax: E-mail:

I will submit a list of radiocarbon measurements (published and/or unpublished) on soils ☐

I am interested in doing a short paper on the interpretation of such results ☐

I would like to contribute data on the following topics (please explain in some detail, attaching a separate sheet of paper, if necessary):

The following people should also be contacted:

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