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A HIGH-RESOLUTION RADIOCARBON CALIBRATION BETWEEN 11,700 AND 12,400 CALENDAR YEARS BP DERIVED FROM ^{230}TH AGES OF CORALS FROM ESPIRITU SANTO ISLAND, VANUATU

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ABSTRACT. This paper presents radiocarbon results from a single *Diploastrea heliopora* coral from Vanuatu that lived during the Younger Dryas climatic episode, between *ca.* 11,700 and 12,400 calendar yr BP. The specimen has been independently dated with multiple ^{230}Th measurements to permit calibration of the ^{14}C time scale. Growth bands in the coral were used to identify individual years of growth. ^{14}C measurements were made on each year. These values were averaged to achieve decadal resolution for the ^{14}C calibration. The relative uncertainty of the decadal ^{14}C data was below 1% (2σ). The data are in good agreement with the existing dendrochronology and allow for high-resolution calibration for most years. Variations in the fine structure of the ^{14}C time series preserved in this specimen demonstrate sporadic rapid increases in the Δ^{14}C content of the surface ocean and atmosphere. Certain sharp rises in Δ^{14}C are coincident with gaps in coral growth evidenced by several hiatuses. These may be related to rapid climatic changes that occurred during the Younger Dryas. This is the first coral calibration with decadal resolution and the only such data set to extend beyond the dendrochronology-based ^{14}C calibration.

INTRODUCTION

The ^{14}C calibration curve commonly used today (Stuiver, Long and Kra 1993) evolved over the past 30 years and represents the efforts of a number of laboratories. The 1993 calibration covers the last 11.4 ka and is based on thousands of ^{14}C measurements of tree rings. The dendrocalibration has recently been extended to *ca.* 11.9 ka (Kromer and Spurk 1998), but beyond this point the tree-ring record is uncalibrated. The existence of relatively old floating Tasmanian tree-ring series should eventually provide a means for extending the existing dendrocalibration in the future (Barbetti *et al.* 1992; Tuniz *et al.* 1997).

Researchers in the field have sought to extend the dendrochronological limit using several alternative methods, including calibration based on counting varved sediments (Wohlfarth 1996; Hughen *et al.* 1998) and calibration using carbonates dated with ^{230}Th, such as corals (Bard *et al.* 1990, 1993; Edwards *et al.* 1993) and speleothems (Vogel and Kronfeld 1997; Goslar *et al.* 1997; Richards *et al.* 1997). Although these studies have produced useful information about past variations in the ^{14}C content of the atmosphere, none of them has approached the resolution and precision of dendrochronology. The purpose of this paper is to extract a high-resolution (decadal) ^{14}C calibration record from coral with precision comparable to the dendrocalibration. This is possible because certain corals are annually banded (see, *e.g.*, Knutson, Buddemeier and Smith 1972) and can be dated very accurately using the ^{230}Th age dating technique (Edwards, Chen and Wasserburg 1987). This is the first study to adopt such a strategy for the purpose of calibration.

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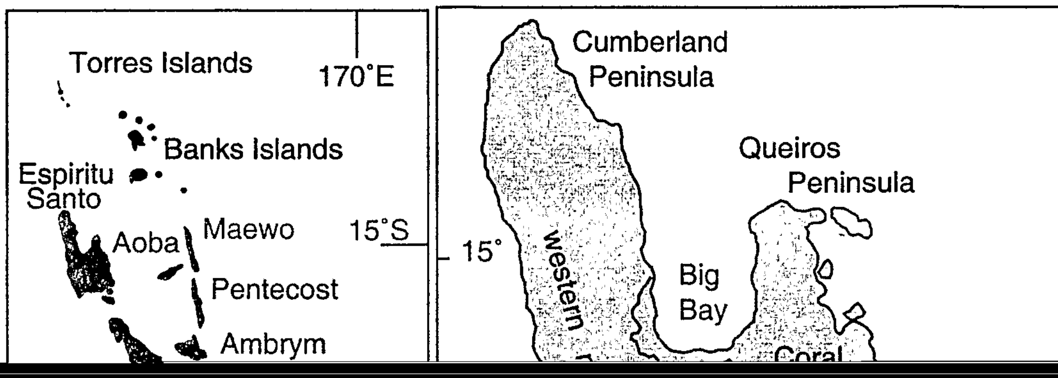
the past 11.9 ka, but it should be emphasized that the reservoir age is affected by the source of surface ocean water and could vary with changing paleo-ocean circulation patterns.



To calculate reservoir-corrected fraction of modern values (F_{RC}), we define the relationship

$$^{14}\text{C age}_{RC} \equiv -\tau \ln F_{RC} \ . \tag{4}$$

Combining equations 2, 3, and 4 yields the expression

$$F_{RC} = F\, e^{RC/\tau} \ . \tag{5}$$

The uncertainty in F_{RC} depends on the uncertainty in F and on the uncertainty in RC. Propagating these two sources of error yields the expression

$$\sigma_{F_{RC}} = \left\{ \left(e^{RC/\tau}\right)^2 (\sigma_F)^2 + \left[\left(\frac{F}{\tau}\right) \left(e^{RC/\tau}\right) \right]^2 (\sigma_{RC})^2 \right\}^{1/2} \tag{6}$$

where the σ's represent the uncertainties in F_{RC}, F, and RC.

$\Delta^{14}C$ values were computed from F_{RC} values. $\Delta^{14}C$ is a relative measure of the $^{14}C/^{12}C$ (or $^{14}C/^{13}C$) content of the atmosphere, as compared with the assumed value for 1950. Positive values indicate an excess relative to 1950 and negative values indicate a relative ^{14}C deficit. $\Delta^{14}C$ values were computed with the expression

$$\Delta^{14}C = (F_{RC}\, e^{\lambda t} - 1)\ 1000‰ \tag{7}$$

where λ is the decay constant for the 5730-yr half-life, and t is the calendar age of the sample in years BP (before 1950), determined with the ^{230}Th technique. This value for $\Delta^{14}C$ is equivalent to the age-corrected value for Δ given in Stuiver and Polach (1977).

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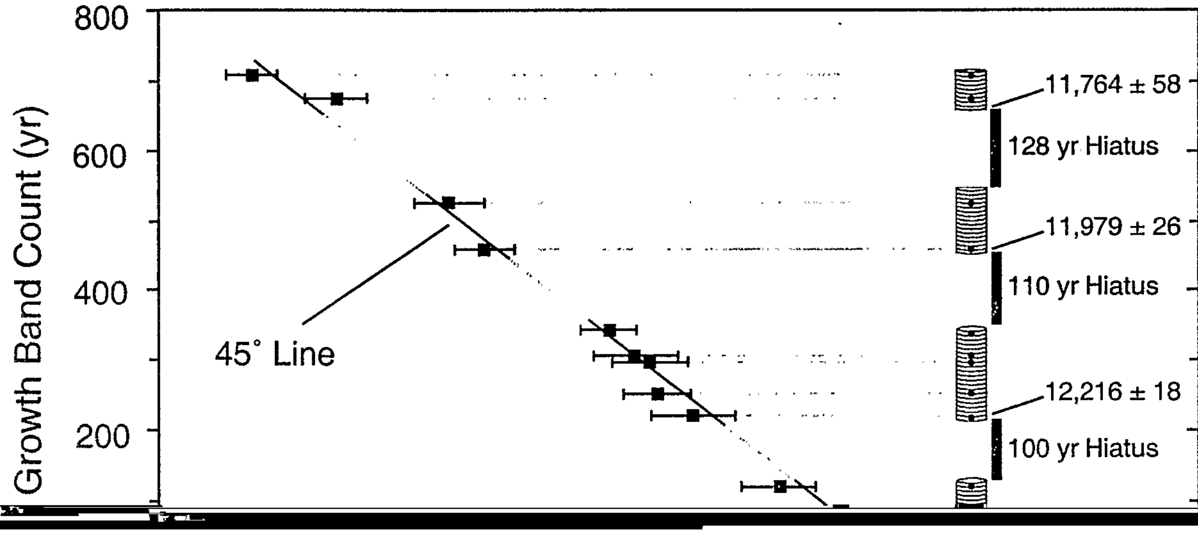
800
600
400
200
Growth Band Count (yr)
45° Line
11,764 ± 58
128 yr Hiatus
11,979 ± 26
110 yr Hiatus
12,216 ± 18
100 yr Hiatus

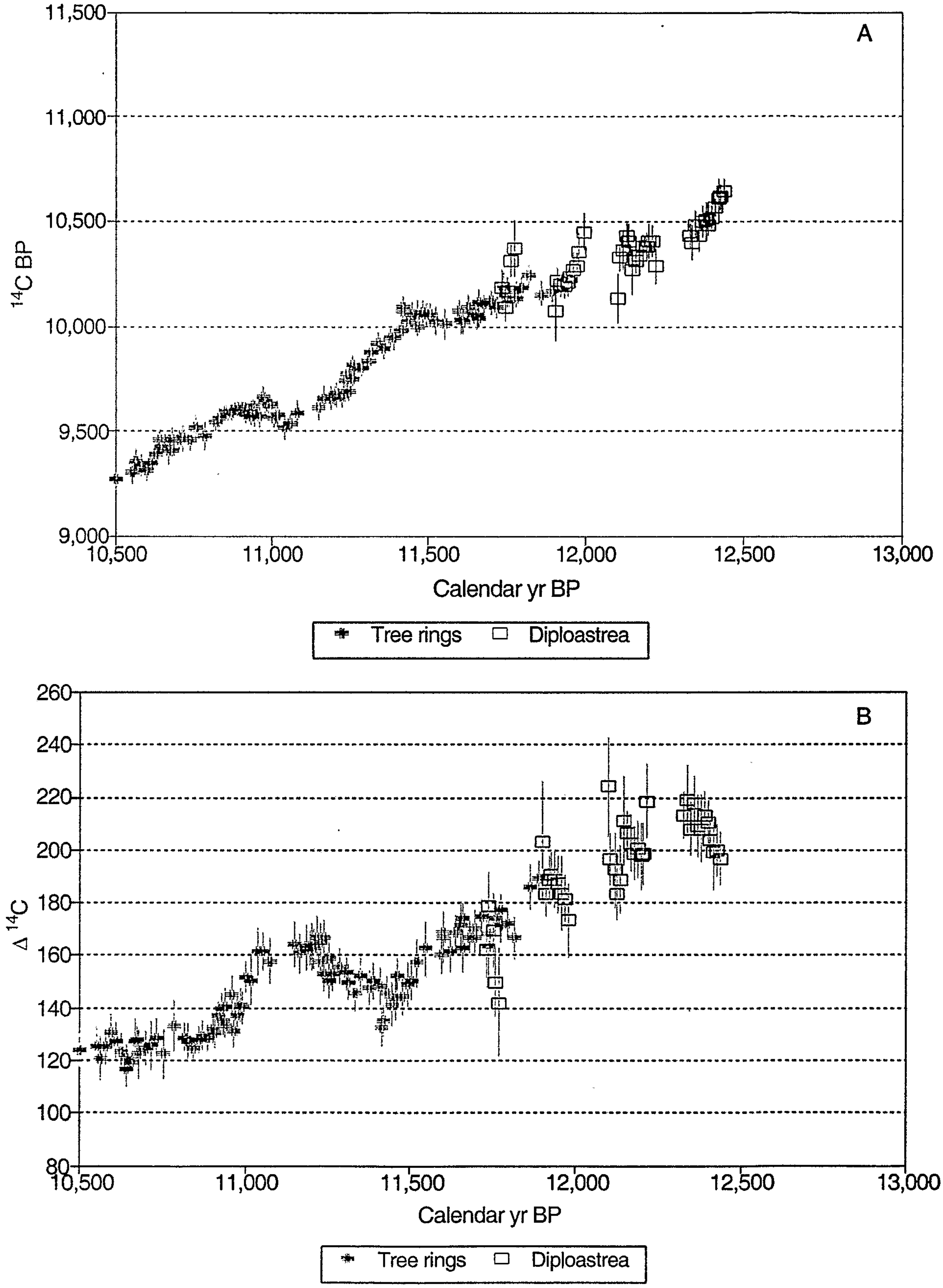

Fig. 3. Comparison of the coral data from this study with the tree ring data of Kromer and Spurk (1998, revised from Kromer and Becker 1993). All uncertainties are 2σ. A. ^{14}C ages; B. Δ^{14}C values.

TABLE 1A. ^{230}Th Results for Individual Years

Sample	^{230}Th age ± 2σ (yr BP)	$\delta^{234}U_{initial}$ ± 2σ	^{238}U (ppm)	^{232}Th (ppt)	Growth band (year number)
Top growth band	Section 4				720
9-11-12.5-b	11,705 ± 29	149.3 ± 1.0	2.357	597.0	710
9-11-12.5	11,800 ± 35	148.8 ± 1.1	2.792	800.0	675
Growth hiatus					**128 ± 64 (2σ)**
Top growth band	Section 3				549
9-12.5-14.0-1	11,928 ± 39	149.3 ± 1.0	2.970	131.0	526
9-12.5-14.0-2	11,968 ± 34	150.7 ± 1.5	2.598	28.2	460
Growth hiatus					**110 ± 32 (2σ)**
Top growth band	Section 2				350
9-12.5-14.0-3a	12,108 ± 32	146.6 ± 1.2	2.542	55.0	345
9-12.5-14.0-3b	12,138 ± 47	148.0 ± 1.1	2.590	1925	306
9-12.5-14.0-3c	12,154 ± 42	152.3 ± 1.5	2.543	49.6	297
9-12.5-14.0-4	12,163 ± 37	148.9 ± 1.3	2.691	104.0	251
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 2. Radiocarbon results. Decadal averages; weighted means from multiple measurements. The number of annual bands averaged for each result is given as n. Uncertainties are 2σ (see text).

^{230}Th age (yr BP)	^{14}C age (yr BP)	Δ^{14}C (‰)	n
11,730	10,189 ± 82	162 ± 14	4
11,740	10,086 ± 69	179 ± 13	10
11,750	10,161 ± 76	169 ± 14	10
11,760	10,308 ± 77	149 ± 13	10
11,770	10,370 ± 138	142 ± 21	2
11,900	10,077 ± 151	203 ± 23	8
11,910	10,219 ± 59	184 ± 9	10
11,920	10,195 ± 58	189 ± 9	10
11,930	10,192 ± 58	190 ± 9	10
11,940	10,212 ± 70	189 ± 11	9
11,950	10,234 ± 70	187 ± 11	10
11,960	10,268 ± 88	184 ± 14	10
11,970	10,290 ± 59	182 ± 9	10
11,980	10,357 ± 89	173 ± 14	4

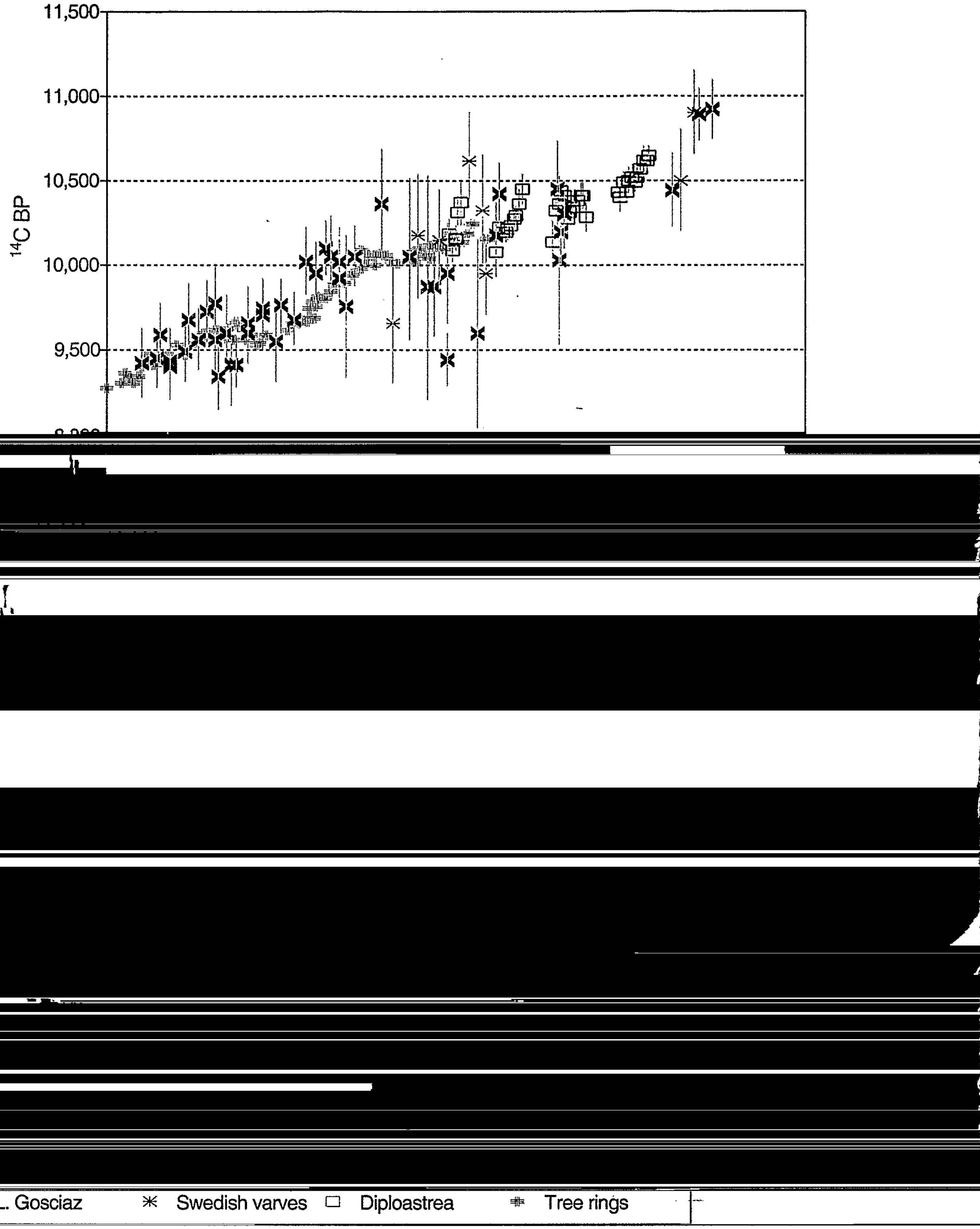

Fig. 5. Comparison of the coral data from this study with European varve data from Sweden (Wohlfarth 1996), and Lake Gościąż, Poland (Goslar *et al.* 1995). All uncertainties are 2σ.

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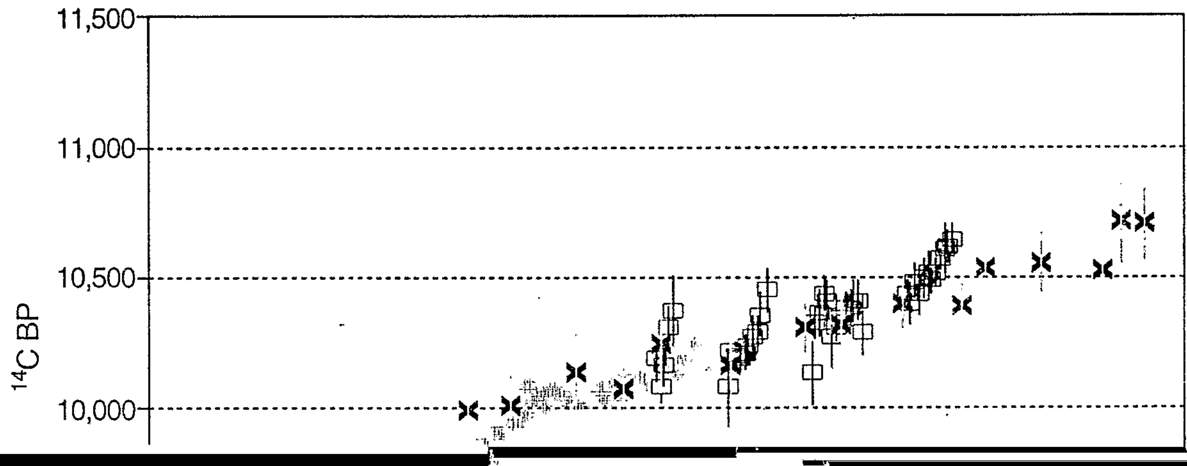
11,500
11,000
10,500
10,000
14C BP

[redacted]