INTRODUCTION

Calibration curves spanning several millennia are now available in this special issue of \textit{Radiocarbon}. These curves, nearly all derived from the \(^{14}\text{C}\) age determinations of wood samples, are to be used for the age conversion of samples that were formed through use of atmospheric \(^{14}\text{C}\) content. When samples are formed in reservoirs (eg, lakes and oceans) that differ in specific \(^{14}\text{C}\) content from the atmosphere, an age adjustment is needed because a conventional \(^{14}\text{C}\) age, although taking into account \(^{14}\text{C}\) (and \(^{13}\text{C}\)) fractionation, does not correct for the difference in specific \(^{14}\text{C}\) activity (Stuiver \& Polach, 1977). The \(^{14}\text{C}\) ages of samples grown in these environments are too old, and a reservoir age correction has to be applied. This phenomenon has been referred to as the reservoir effect (Stuiver \& Polach, 1977).

The reservoir age, or apparent age, \(R(t)\) is here defined as the difference between conventional \(^{14}\text{C}\) ages of samples grown contemporaneously in the atmosphere and the other carbon reservoir. \(R(t)\) is not constant (\(t = \) cal age) because the difference in reservoir and atmosphere \(^{14}\text{C}\) specific activity is liable to change with changes in reservoir parameters (such as size of the carbon pool, input and output fluxes and exchange with the atmosphere) and atmospheric \(^{14}\text{C}\) values. However, due to the lack of detailed information, a variable reservoir age correction usually cannot be applied, and the user of \(^{14}\text{C}\) ages then resorts to the assumption of a constant reservoir age correction \(R^*\) (ie, the reservoir \(^{14}\text{C}\) specific activity is assumed to parallel atmospheric \(^{14}\text{C}\) specific activity at all times). The reservoir age correction \(R^*\) is obtained from the conventional \(^{14}\text{C}\) age of reservoir samples of either historically known age, or of inferred known age (such as the uppermost portion of lake sediment). This approach is, of course, only a first order approximation. However, even though the resulting reservoir corrected \(^{14}\text{C}\) age is not the ultimate in accuracy, the corrected \(^{14}\text{C}\) age should be closer to the \(^{14}\text{C}\) age of a contemporaneous wood sample than the uncorrected one.

The recent introduction of the dating of mg C samples through AMS (accelerator mass spectrometry) allows for an improved determination of variable reservoir ages \(R(t)\) in lakes because it is now possible to measure, at different depths, the age differences between 1) those plant macrofossils that were originally utilizing atmospheric \(^{14}\text{CO}_2\), 2) lake carbonate, and 3) gyttja. The first study of this kind has been made for the sediments of a small closed basin of the Lobsingsee, Switzerland (Andrée \textit{et al}, 1986b). Here the problem of reservoir age corrections can be avoided entirely if a sufficient number of macrofossils formed directly from atmospheric \(^{14}\text{CO}_2\) can be found.

For small carbon reservoirs where the exchange rate with the atmosphere is dominant (eg, a shallow 10ha lake) the change in specific \(^{14}\text{C}\) content may well parallel the observed change in atmospheric \(^{14}\text{C}\) content. For other reservoirs, however, appreciable differences are possible. For instance, the top 75m of the ocean (well mixed due to wave action, etc) attenuates atmospheric decadal \(^{14}\text{C}\) changes strongly due to its inertia in responding to atmospheric forcing, and the deep ocean lags appreciably in its response to long-term atmospheric \(^{14}\text{C}\) change. The idea of a constant reservoir age correction \(R^*\) is not tenable in this case.

The reservoir age of marine shells has been determined in the past from the conventional \(^{14}\text{C}\) age of shells of known historic age (year AD X), after correcting for fossil fuel \(^{14}\text{CO}_2\)-induced \(^{14}\text{C}\) age change in the mixed layer of the ocean (Mangerud \& Gulliksen, 1975; Robinson \& Thompson, 1981). This fossil fuel corrected \(^{14}\text{C}\) age is then compared with the age of the sample, ie, 1950 – X, and the difference is the reservoir or apparent age. This procedure assumes constant atmospheric \(^{14}\text{C}\) level, where calendar years and \(^{14}\text{C}\) years are interchangeable. Thus, the reservoir age in this instance is the fossil fuel corrected shell \(^{14}\text{C}\) age minus the \(^{14}\text{C}\) age of a sample formed from atmospheric \(^{14}\text{CO}_2\) in AD X.

Olsson (1980), in addition, discusses the \(^{14}\text{C}\) ages of samples formed from atmospheric \(^{14}\text{CO}_2\) of the 19th century, and compares these with the conventional shell \(^{14}\text{C}\) ages. The difference again is the apparent or reservoir age. But, as noted by Olsson, “in this discussion, it has been tacitly assumed that the aim is to arrive at a reservoir effect that is not affected by short-term fluctuations of radiocarbon in the atmosphere.”

Two avenues of age calibration are possible for a sample formed in a fluctuating \(^{14}\text{C}\) environment. One is to derive the variable reservoir age \(R(t)\) in conventional \(^{14}\text{C}\) years, apply this correction to obtain a reservoir corrected \(^{14}\text{C}\) age, and then use the calibration curves valid for samples formed directly from atmospheric \(^{14}\text{CO}_2\). The other is to produce a separate calibration curve that includes the variability in reservoir ages. Such a curve gives the conventional \(^{14}\text{C}\) age minus a \(\Delta R\) number (explained later on) \(\text{vs}\) the cal BP (cal AD/BC) age. We here follow the latter approach for marine samples.

A box-diffusion model as described by Oeschger \textit{et al} (1975) was used to simulate global carbon exchange. We attribute the observed atmospheric \(^{14}\text{C}\) variability of the last 9000 yr to solar (heliomagnetic) and geomagnetic modulation of the cosmic ray flux (Stuiver \& Quay, 1980; Sernberg \& Damon, 1983), and consider model parameter change induced by oceanic (climate) change to be negligible over this time interval (Andrée \textit{et al}, 1986a). The observed atmospheric \(^{14}\text{C}\) record is used to calculate the \(^{14}\text{C}\) content of the mixed layer (top 75m) of the model ocean, and the model mixed layer \(^{14}\text{C}\) ages are plotted \(\text{vs}\) cal AD/BC (cal BP) ages. The calibration curves are different from those given elsewhere in this issue because the \(^{14}\text{C}\) ages are not directly measured but calculated from the atmospheric record.
through carbon reservoir modeling. The curves therefore not only reflect
the original measuring uncertainty in the wood $\Delta^{14}C$ values that constitute
the model input, but also uncertainties in model parameters.

THE GLOBAL CARBON MODEL

The atmospheric $\Delta^{14}C$ data used as input for the model span the AD
1950–7746 BC interval. A composite data set (Fig 1) was derived by combining
the data of Stuiver and Pearson (1986) for the AD 1950–500 BC interval, of
5346 BC and 5818–5882 BC, of Stuiver et al (1986) for 5685–5815 BC,
5675 BC and 6205–6275 BC. The Figure 1 data represent average $\Delta^{14}C$
values of 20-yr samples back to 5220 BC, and of a mixture of intervals (single yr
to up to 20 yr) prior to that.

Detailed atmospheric $\Delta^{14}C$ on a decadal scale is given in Figure 2 for
the last 4500 yr (Stuiver & Becker, 1986).

For the carbon reservoir modeling, we constructed a curve with bi-
decadal coverage for the entire AD 1950–7740 BC interval. The initial equi-
librium conditions of the model were set at an atmospheric $\Delta^{14}C$ value of
+90%o (Stuiver et al, 1986). An important parameter of the box-diffusion
model (see also Stuiver & Quay, 1981) is the atmospheric CO$_2$ concentration
which is fixed at 280ppm (Neftel et al, 1985; Stuiver, Burck & Quay,
1984). Oceanic C is fixed at 2.31mole/m$^2$ (Takahashi, Broecker & Bainbridge,
1981). The biosphere is set at a constant 1900
Gigatons C (Olson, Pflüger & Chan, 1978). The biosphere is divided into
two reservoirs with residence times of 2.7 yr and 80 yr (Emanuel et al,
1984). The reservoir with fast turnover contains 10.6% of the total biomass,
the other 89.4% (Emanuel et al, 1984). Gas exchange rate F is set at 19moles/m$^2$yr in order to yield a nearly 50% $\Delta^{14}C$ difference between the
atmosphere and mixed layer in the year 1830 (the last bi-decadal midpoint
without fossil fuel CO$_2$ influence). To generate a 40% difference between
the atmospheric and mixed layer $\Delta^{14}C$, F has to be adjusted to 24moles/
m$^2$yr.

A vertical diffusion coefficient K$_v$ of 1.26cm$^2$/sec yields a deep ocean
$\Delta^{14}C$ value of $-190$%o in 1850, in agreement with GEOSECS measure-
ments (Stuiver, Quay & Osthund, 1983).

MODEL RESULTS

The model input is the post-7750 BC atmospheric $\Delta^{14}C$ record, of
which the post-7200 BC portion is given in the top curve of Figure 3. The
$\Delta^{14}C$ values of the 550 yr preceding 7200 BC (Fig 1) were used for a proper
startup of the model.

Model-derived mixed layer $\Delta^{14}C$ values (F = 19mole/m$^2$yr, K =
1.26cm$^2$/sec, to yield a mixed layer $\Delta^{14}C = -49.7$%o (R = 409 yr) at AD
1830) are given in the middle curve. Relative to the atmosphere, there is a
substantial attenuation of the higher $\Delta^{14}C$ frequencies in the mixed layer.
For the deep ocean (bottom curve) only a long-term trend remains.

To determine the sensitivity of the model results to the choice of F and
K, we also generated mixed layer $\Delta^{14}C$ values with model parameters set
at F = 24mole/m$^2$yr, K = 1.26cm$^2$/sec, to yield a mixed layer $\Delta^{14}C =
-40.4$%o (R = 331 yr) at AD 1830. The difference between the F = 19 and
F = 24mole/m$^2$yr model outputs of mixed layer $\Delta^{14}C$ values and $14C$ ages
are given in Figure 4. Evidently the calibration curve is relatively insensitive
to F because the model-calculated mixed layer ages, after normalization on
the same baseline, differ by up to 16 $^14C$ years.

Eddy diffusivity is faster in the upper portion of the ocean than in the
lower part (Stuiver, 1980). We compared the model-generated mixed layer
$\Delta^{14}C$ ages for K, values of 1.26cm$^2$/sec and 2.2cm$^2$/sec, with R set at 409 yr in
AD 1830 in both cases. The faster diffusivity was accompanied by an
increased exchange coefficient F of 20moles/m$^2$yr. The resulting model
outputs of mixed layer $\Delta^{14}C$ ages differed by a fraction of a decade for the
long term (millennia), as well as the shorter term (century) type oscillations.
Thus, the fine structure of the model mixed layer curves is not sensitive to
assumed K, values.

Figure 5 gives the conventional $14C$ ages of the atmosphere, mixed
layer of the ocean, and the deep ocean. The differences in basic features of
the atmospheric and marine calibration curves are caused by the strong
attenuation in the oceans of the higher frequency $\Delta^{14}C$ perturbation. This
leads to the variable R(t). With the traditional method of correcting marine
$14C$ ages one would deduct a fixed reservoir age R* (derived for one year
only) from the Figure 5 results and use it for all ages. Two examples of this
approach are given in Figures 6 and 7 where fixed reservoir ages of 409 yr
and 1684 yr are deducted from, respectively, the mixed layer and deep
ocean $14C$ ages. The deducted reservoir ages are those calculated for the
year 1830. Whereas the fixed reservoir age concept indeed gives calibration
curves resembling the atmospheric one for the 4300–5000 BC interval (Fig
6), appreciable differences are found for the 200–900 BC interval (Fig 7).
This is due partially to the perturbation in atmospheric $\Delta^{14}C$ between 400
and 750 BC which results in the horizontal portion of the Figure 7 atmos-
pheric calibration curve. This perturbation is much smaller in the mixed
layer, and absent in the deep ocean (Fig 7). Similarly, the lag in deep ocean
response to the long-term post 5000 BC atmospheric $\Delta^{14}C$ decline results in
the lower curve offset in Figure 7.

Atmospheric $\Delta^{14}C$ changes in our model are caused by production rate
changes. The atmospheric $\Delta^{14}C$ changes in turn influence the oceans. A
reverse scenario in which changes in ocean circulation lead to atmospheric
$\Delta^{14}C$ changes is contradicted by the work of Andrée et al (1986a) on the $14C$
age differences of the mixed layer and the deep ocean. These age differences
were derived from the $14C$ ages of planktonic and benthic marine
organisms in two sediment cores of the South China Sea (Fig 8). As dis-
cussed by Andrée et al (1986a), a drastic post 6000 BP speed-up in ocean
circulation is needed if the oceans would be the primary cause of the long-
term change (Fig 1) in atmospheric $\Delta^{14}C$ values. For this scenario a much lower rate of ocean mixing is needed in the early Holocene which would generate $^{14}C$ age differences twice as large as currently found between mixed layer and deep ocean (Andrée et al., 1986a). As this is not the case (Fig 8), our first order assumption of constant reservoir parameters is justified. It should be noted, however, that even with a fixed mode of ocean circulation, changes of up to 200 yr are possible in the mixed layer-deep sea Holocene $^{14}C$ age differences (Fig 8).

The variable reservoir ages $R(t)$ of the mixed layer and deep ocean deduced from Figure 5 are given in Figure 9A. The atmospheric $\Delta^{14}C$ lowering associated with fossil fuel combustion decreases the reservoir age of the mixed layer and deep ocean by about, respectively, 100 yr and 170 yr between AD 1850 and 1950 (Fig 9B).

**RADIOCARBON AGE CALIBRATION AND $\Delta R$ DETERMINATION**

The question arises how a user provided with a conventional $^{14}C$ age of a sample from a certain part of the ocean should use the calibration curves that are calculated for the world oceans. After proper correction for isotope fractionation (Stuiver & Polach, 1977), the conventional $^{14}C$ ages of marine shells are generally too old. The age anomaly (reservoir age) is 200 to 400 yr for the mixed layer of the world oceans, but may be larger in areas of upwelling (up to 1300 yr, Stuiver & Brazzanas, 1985).

Our calibration curves depict the relationship between cal AD/BC (cal BP) ages and conventional (Stuiver & Polach, 1977) $^{14}C$ ages. Those $^{14}C$ ages are corrected for isotope fractionation, but not for any reservoir deficiency. The model mixed layer and deep ocean reservoir ages average, respectively, 373 yr and 1554 yr over the last 9000 yr. These averages reflect from our choice of specific model parameters and do not reflect local variations in the ocean reservoir ages.

To accommodate local effects, the model ocean can be matched with regional parts of the world ocean by assuming a parallel $\Delta^{14}C$ response, i.e., we assume as a first approximation identical time-dependent response of the regional and world ocean to atmospheric forcing. Further refinement would be possible if each region could be modeled separately. However, we have to work at present with the above approximation.

The reader of the previous sections will have noticed the time-dependent character of the reservoir age $R(t)$ of the mixed layer of the ocean. The reservoir age, or the conventional $^{14}C$ age, time-dependent because the oceanic $\Delta^{14}C$ response to atmospheric $\Delta^{14}C$ forcing differs from the atmospheric signal. However, an approximately parallel response to atmospheric forcing of a regional part of the ocean and the world ocean results in a constant difference ($\Delta R$) in reservoir age of the two. Thus, although reservoir ages are time-dependent, $\Delta R$, as a first approximation, is not.

The difference $\Delta R$ in reservoir age of the regional part of the ocean from which the users sample is derived, and the reservoir age of our model ocean, is determined through the use of Figure 10A. The user needs information on reservoir ages, i.e., a $^{14}C$ age P should be available for a historic (year AD X) sample collected from the same reservoir from which his/her sample is derived. The user has to derive from Fig 10A the model mixed layer (or deep ocean) $^{14}C$ age Q for year AD X. The correction factor to be used for the sample $^{14}C$ age in the calibration Figures 11 and 12 is then $\Delta R = P - Q$.

In case the user lacks information on $^{14}C$ ages of historic samples he/she can assume the sample comes from an environment similar to the model world ocean. The Figure 11 and 12 calibration curves (with $\Delta R = 0$) can then be used directly.

Our calculations neglect hemispheric reservoir differences that cause $^{14}C$ ages of atmospheric samples of the Southern Hemisphere to be ca 30 years older than those of the Northern Hemisphere. Hemispheric differences will be taken into account in a model currently being developed by one of us (T Brazzanas).

Suggested $\Delta R$ values for various oceanic regions are plotted in Figure 10B. These weighted mean $\Delta R$ values were derived from $^{14}C$ ages listed in Table 1, which also gives the sample groupings from which the average $\Delta R$ values were derived. Except for a few instances, Table 1 contains only shell sample dates.

The standard deviations given with $\Delta R$ in Table 1 were derived from the errors reported with the $^{14}C$ ages. The $^{14}C$ age groupings also can be viewed as a data set from which the standard deviation ("scatter" sigma) in the unweighted mean can be calculated. These "scatter" sigmas in the unweighted mean are given in Table 1.

The largest of each set of sigmas was used for the $\pm$ value plotted in Figure 10B. In view of the much debated under-reporting of $^{14}C$ age errors, it was gratifying to see that the scatter sigma was, on average, only 1.1 times the $^{14}C$ age sigma. From this we conclude 1) the additional uncertainty in $\Delta R$ introduced by non-uniform $^{14}C$ content of the regional ocean reservoirs is small, and 2) the age errors given for the Table 1 shell samples are realistic estimates of the measurement precision.

The uncertainty in the age conversion process depends on the extent to which a particular sample’s environment resembles the average model world ocean, and on the degree to which the model simulates the reality. It is not possible to give these uncertainties as standard deviations, and the calibration curves therefore lack an uncertainty band.

When converting a conventional $^{14}C$ age into cal AD/BC (or cal BP) age, the standard deviation in the sample age determination $\sigma_s$ should be taken into account. There will be an additional error in either the determined or the assumed reservoir age difference $\Delta R$. As noted, $\Delta R = P - Q$ where $P$ is the conventional $^{14}C$ age of an historic sample, and $Q$ the model-calculated conventional $^{14}C$ age of a sample of the same historic age. The $\Delta R$ error ($\sigma_{\Delta R}$) depends on the error in $P$, as well as $Q$. We do not have a standard error for the model-calculated $Q$ value. Only a lower limit can be given for $\sigma_{\Delta R}$ by substituting the error in the $^{14}C$ age determination $P$. This error is listed in Table 1 as a “minimum estimate" for $\sigma_{\Delta R}$.

The $\sigma_{\Delta R}$ should be combined with $\sigma_s$ according to $\sigma_{\Delta R}^2 = \sigma_{R}^2 + \sigma_s^2$. The
(14C age – ΔR) ± σtotal, after conversion, determines a minimum range in calibrated ages.

Marine and “atmospheric” samples with identical 14C ages and standard deviations will differ in calibrated age, as well as in the range in calibrated ages. The cal range will usually be larger for the marine sample due to the incorporation of the standard deviation σR in the reservoir age difference ΔR. The issue of multiple intercepts, however, is much less important for marine samples because the calibration curves (Figs 11, 12) are much less wiggly than the corresponding atmospheric ones (eg, Stuiver & Pearson, 1986).

ACKNOWLEDGMENTS

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Fig 1. Atmospheric $\Delta^{14}C$ vs age. Compiled from data sources given in the text.
The average standard deviation of the decadal measurements is 2.6‰.

Fig 2. Atmospheric Δ¹⁴C of the past 4½ millennia for each decade (Stuiver & Becker, 1986).
Fig 3. Atmospheric Δ¹⁴C (bi-decadal values) as used for the model calculations and calculated mixed layer and deep ocean Δ¹⁴C values.
Fig 5. $^{14}$C ages of the atmosphere (bi-decadal values) and calculated conventional $^{14}$C ages of the mixed layer and deep ocean.
The fixed reservoir correction was 409 yr and 1684 yr, respectively, the mixed layer and the deep ocean.

Fig 6. $^{14}C$ ages of "atmospheric" samples compared to reservoir corrected mixed layer and deep ocean $^{14}C$ ages for the 4300-5000 BC interval.
Fig. 7. Similar to Figure 6 for the years 200-900 BC.
Fig 8. The calculated deep ocean-mixed layer $^{14}$C age differences compared to benthic-planktonic differences measured by Andrée et al (1986a) for the South China Sea. The deep water in the China Sea is more $^{14}$C-deficient than our model ocean, causing a shift between the $^{14}$C time scales of 1585 (latest pre-anthropogenic age difference in Andrée et al) minus 1275 $^{14}$C years (model an 1830 value), both indicated by the dotted line.
Fig 9. The changing pattern of model-calculated reservoir ages $R(t)$ of the mixed layer (top curve) and the deep ocean (bottom curve).
Fig 9B. Model calculated reservoir age for the mixed layer of the ocean (upper curve) and the deep ocean (lower curve).
Fig 10A. Model-calculated conventional $^{14}$C ages of the mixed layer and deep ocean for the AD 1600–1950 interval.
Coastal regions $\Delta R$ values in $^{14}C$ yr as derived mostly from shell dates. The $\pm$ values are minimum standard deviations based on the scatter of the data, or the measurement precision, whichever is larger (see Table 1 for details).
Fig 11. Mixed layer conventional 14C ages vs cal AD/BC (cal BP) ages. The value to be substituted for AR is discussed in the text.
MARINE MIXED LAYER

AND BRAZUNAS

STIVER, PEARSON

CONVENTIONAL RADIOCARBON AGE - ΔR (YRS BP)

0°11B

AD 0°1

900 1000 1100 1200 1300 1400 1500 1600

0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600

BP
MARINE MIXED LAYER

CONVENTIONAL RADIOCARBON AGE - ΔR (YRS BP)

Fig 11
Fig. 11

STUIVER, PEARSON, AND BRAZIUNAS

MARINE MIXED LAYER

CONVENTIONAL RADIOCARBON AGE - \Delta R (YRS BP)
Fig 11H

AND BRAZIUNAS

STIVER, PEARSON

HIGH 401 BC

2100 2000 1900 1800 1700 1600 1500 1400

MARINE MIXED LAYER

CONVENTIONAL RADIOCARBON AGE - ΔR (YRS BP)

4100 4000 3900 3800 3700 3600 3500 3400 3300 3200 3100 3000 2900 2800 2700 2600 2500 2400 2300 2200 2100

001 BP
STUIVER, PERSON, AND BRAZIUAS

MARINE MIXED LAYER

CONVENTIONAL RADIOCARBON AGE - \( \Delta R \) (YRS BP)

BP
CONVENTIONAL RADIOCARBON AGE \(-\Delta R\) (YRS BP)

Fig 11

STUIVER, PEARSON, AND BRAZUNAS

MARINE MIXED LAYER

cal BC
CONVENTIONAL RADIOCARBON AGE - ΔR (YRS BP)

Fig. 1

STUIVER, PEARSON, AND BRAZIUNAS

MARINE MIXED LAYER

STUIVER, PEARSON, AND BRAZIUNAS
CONVENTIONAL RADIOCARBON AGE - ΔR (YRS BP)

MARINE MIXED LAYER

STUIVER, PEARSON, AND BRAZUNAS
Figure 1

AD AND BRUNINGA.

STUIVER, POWSON,

MARINE MIXED LAYER

CONVENTIONAL RADIOCARBON AGE - ΔR (YRS BP)

10,000 7,000 6,000 5,000 4,000 3,000 2,000 1,000 0

BP
MARINE MIXED LAYER

AND BRIZIUS,

STUIVER, PEARSON.
Fig 12. Deep ocean conventional 14C ages vs cal AD/BC (cal BP) ages. ZSR is discussed in the text.
Radiocarbon Age Calibration of Marine Samples Back to 9000 cal yr BP

Table 1

Marine radiocarbon ages and ΔR values of mostly shell samples of known historic age

<table>
<thead>
<tr>
<th>MARINE SHELLS</th>
<th>HISTORICAL AGE (cal AD)</th>
<th>CONVENTIONAL SAMPLE 14C AGE (14C YRS BP)</th>
<th>ΔR (14C YRS BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>REFb REGIONc</strong></td>
<td><strong>SAMPLE #</strong></td>
<td><strong>14C AGE</strong></td>
<td><strong>(14C YRS BP)</strong></td>
</tr>
<tr>
<td>11.9 Diabaavtika, Lagoya, Spitsbergen 80°34'N 18°03'E</td>
<td>U-121</td>
<td>1958 E</td>
<td>670±80</td>
</tr>
<tr>
<td>11.9 NE side of Nordre, Russoya, Murchisonfjorden, Spitsbergen 80°00'N 18°09'E</td>
<td>U-122</td>
<td>1958 E</td>
<td>430±80</td>
</tr>
<tr>
<td>10 Magdalenafj., Spitsbergen 79°34'N 10°00'E</td>
<td>T-1541</td>
<td>1878</td>
<td>632±70</td>
</tr>
<tr>
<td>11.9 Tangen, Mushamna, Spitsbergen 79°30'N 14°00'E</td>
<td>U-133</td>
<td>1952 E</td>
<td>530±70</td>
</tr>
<tr>
<td>10 Adventbukta, Spitsbergen 78°15'N 15°36'E</td>
<td>T-1540</td>
<td>1878</td>
<td>622±70</td>
</tr>
<tr>
<td>10 Isfjorden, Spitsbergen 78°07'N 14°08'E</td>
<td>T-1539</td>
<td>1925</td>
<td>519±50</td>
</tr>
<tr>
<td>10 Bellsund, Spitsbergen ca. 77°40'N 14-16°E</td>
<td>T-1538</td>
<td>1926</td>
<td>549±50</td>
</tr>
<tr>
<td>10 Near Bear Island 74°07'N 19°00'E</td>
<td>T-1537</td>
<td>1900</td>
<td>523±50</td>
</tr>
</tbody>
</table>

**WEIGHTED MEAN OF ABOVE 8 SAMPLES**
**SCATTER ± IN UNWEIGHTED MEAN IS 19 25 YR**
70±20

| 10 Rice Strait, Smith Sound, Ellesmere Island 78°45'N 74°55'E | T-1544 | 1898 | 744±70 | 266±70 |
| 10 Goose Bay, Jones Sound, Ellesmere Island ca. 76°45'N 89°00'E | T-1543 | 1900 | 893±70 | 416±70 |
| 10 Havnefjorden, Jones Sound, Ellesmere Island 76°30'N 84°30'E | T-1542 | 1899 | 774±70 | 297±70 |

**WEIGHTED MEAN OF ABOVE 3 SAMPLES**
**SCATTER ± IN UNWEIGHTED MEAN IS 45 YR**
325±40

<p>| 8 S of L. Pendulumaen and SE of Claveringtoen, NE Greenland 74°35'N 18°23'W and 74°10'N 20°08'W | Lu-650 | 1899 | 591±38 | 114±38 |
| 8 Mackenziebugt, NE Greenland 73°28'N 21°30'W | Lu-609 | 1900 | 650±47 | 173±47 |
| 8 Mackenziebugt, NE Greenland 73°28'N 21°30'W | Lu-610 | 1900 | 620±54 | 143±54 |</p>
<table>
<thead>
<tr>
<th>REF</th>
<th>REGION</th>
<th>SAMPLE #</th>
<th>HISTORICAL AGE (cal AD)</th>
<th>CONVENTIONAL AGE $^{14}$C AGE ($^{14}$C YRS BP)</th>
<th>$^{14}$C AGE DR ($^{14}$C YRS BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Fame Oer, Scoresby Sund, NE Greenland</td>
<td>Lu-643</td>
<td>1899</td>
<td>641±39</td>
<td>164±39</td>
</tr>
<tr>
<td>17</td>
<td>S cove, Nw, NE Greenland (ca. 72°N 23°W)</td>
<td>Y-606</td>
<td>1957</td>
<td>550±70</td>
<td>60±70h</td>
</tr>
<tr>
<td>10</td>
<td>Tanafjord, Finnmark, N Norway</td>
<td>T-1535</td>
<td>1876</td>
<td>584±70</td>
<td>91±70</td>
</tr>
<tr>
<td>9</td>
<td>Konafjord, Finnmark, N Norway</td>
<td>T-958</td>
<td>1922</td>
<td>548±75</td>
<td>75±75</td>
</tr>
<tr>
<td>10</td>
<td>Vadso, Finnmark, N Norway</td>
<td>T-1536</td>
<td>1857</td>
<td>543±50</td>
<td>61±50</td>
</tr>
<tr>
<td>10</td>
<td>Tromso, Troms, N Norway</td>
<td>T-1534</td>
<td>1857</td>
<td>553±50</td>
<td>51±50</td>
</tr>
<tr>
<td>8</td>
<td>Fame Oer, Scoresby Sund, NE Greenland</td>
<td>Lu-643</td>
<td>1899</td>
<td>641±39</td>
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<td>17</td>
<td>S cove, Nw, NE Greenland (ca. 72°N 23°W)</td>
<td>Y-606</td>
<td>1957</td>
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<td>60±70h</td>
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<td>Tanafjord, Finnmark, N Norway</td>
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<td>Konafjord, Finnmark, N Norway</td>
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<td>1922</td>
<td>548±75</td>
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<td>543±50</td>
<td>61±50</td>
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<td>T-1534</td>
<td>1857</td>
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<td>51±50</td>
</tr>
<tr>
<td>3</td>
<td>Faxa Bay, Kollafjord, Iceland</td>
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<td>1946</td>
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<tr>
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<td>Faxa Bay, Kollafjord, Iceland</td>
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<td>715±51</td>
<td>203±51</td>
</tr>
<tr>
<td>9</td>
<td>Fjaerland fsjorden, Sogn, Norway</td>
<td>T-953</td>
<td>1909</td>
<td>541±80</td>
<td>70±80</td>
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<tr>
<td>9</td>
<td>Leikanger, Sognefjord, Norway</td>
<td>T-951</td>
<td>1912</td>
<td>438±75</td>
<td>33±75</td>
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<tr>
<td>9</td>
<td>Yangnes, Sognefjord, Norway</td>
<td>T-952</td>
<td>1920</td>
<td>500±75</td>
<td>27±75</td>
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<tr>
<td>9</td>
<td>North Sea, approx. half way btwn Bergen and Shetland</td>
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<td>1906</td>
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<td>Vikingbank, North Sea</td>
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<tr>
<td>9</td>
<td>Ideosen, Hordla, Hordaland, Norway</td>
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<td>457±60</td>
<td>-16±60</td>
</tr>
<tr>
<td>9</td>
<td>Sollesnes, Jondal, Hardanger, Norway</td>
<td>T-955</td>
<td>1908</td>
<td>532±75</td>
<td>61±75</td>
</tr>
<tr>
<td>9</td>
<td>Mosterhavn, Hordaland, Norway</td>
<td>T-956</td>
<td>1918</td>
<td>402±90</td>
<td>-70±90</td>
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<tr>
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<td>L-576H</td>
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<td>Faxa Bay, Kollafjord, Iceland</td>
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<td>Faxa Bay, Kollafjord, Iceland</td>
<td>L-576I</td>
<td>1860</td>
<td>715±51</td>
<td>203±51</td>
</tr>
<tr>
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<td>Ideosen, Hordla, Hordaland, Norway</td>
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<td>1923</td>
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<td>Sollesnes, Jondal, Hardanger, Norway</td>
<td>T-955</td>
<td>1908</td>
<td>532±75</td>
<td>61±75</td>
</tr>
<tr>
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<td>Mosterhavn, Hordaland, Norway</td>
<td>T-956</td>
<td>1918</td>
<td>402±90</td>
<td>-70±90</td>
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<td>1908</td>
<td>532±75</td>
<td>61±75</td>
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<tr>
<td>9</td>
<td>Mosterhavn, Hordaland, Norway</td>
<td>T-956</td>
<td>1918</td>
<td>402±90</td>
<td>-70±90</td>
</tr>
</tbody>
</table>

**WEIGHTED MEAN OF ABOVE 5 SAMPLES SCATTER o IN UNWEIGHTED MEAN IS 20 YR**

**WEIGHTED MEAN OF ABOVE 4 SAMPLES SCATTER o IN UNWEIGHTED MEAN IS 10 YR**

**WEIGHTED MEAN OF ABOVE 3 SAMPLES SCATTER o IN UNWEIGHTED MEAN IS 45 YR**

**WEIGHTED MEAN OF ABOVE 8 SAMPLES SCATTER o IN UNWEIGHTED MEAN IS 15 YR**

**WEIGHTED MEAN OF ABOVE 6 SAMPLES SCATTER o IN UNWEIGHTED MEAN IS 25 YR**

**WEIGHTED MEAN OF ABOVE 8 SAMPLES SCATTER o IN UNWEIGHTED MEAN IS 25 YR**

**VALUE USED ON MAP FOR ABOVE SAMPLE**

**WEIGHTED MEAN OF ABOVE 8 SAMPLES SCATTER o IN UNWEIGHTED MEAN IS 25 YR**

**VALUE USED ON MAP FOR ABOVE SAMPLE**
### TABLE 1 (continued)

<table>
<thead>
<tr>
<th>MARINE SHELLS&lt;sup&gt;a&lt;/sup&gt;</th>
<th>REGION&lt;sup&gt;c&lt;/sup&gt;</th>
<th>SAMPLE #</th>
<th>HISTORICAL AGE (cal AD)&lt;sup&gt;d&lt;/sup&gt;</th>
<th>CONVENTIONAL SAMPLE&lt;sup&gt;14&lt;/sup&gt;C AGE (14C YRS BP)&lt;sup&gt;e&lt;/sup&gt;</th>
<th>(14C YRS BP)&lt;sup&gt;f&lt;/sup&gt;</th>
<th>AR</th>
<th>SCATTER σ IN UNWEIGHTED MEAN IS 35 YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 Sooke, British Columbia, Canada</td>
<td>USGS-170</td>
<td>1916</td>
<td>850±50</td>
<td>378±50</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>14 Esquimalt, British Columbia, Canada</td>
<td>USGS-133</td>
<td>1930</td>
<td>750±50</td>
<td>275±50</td>
<td></td>
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<tr>
<td>14 Yaquina Bay, Oregon, USA</td>
<td>USGS-169</td>
<td>1916</td>
<td>840±35</td>
<td>368±35</td>
<td></td>
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<tr>
<td>14 Yaquina Bay, Oregon, USA</td>
<td>USGS-189</td>
<td>1916</td>
<td>835±50</td>
<td>363±50</td>
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<tr>
<td>14 Sunset Bay, Oregon, USA</td>
<td>USGS-233</td>
<td>1936</td>
<td>895±50</td>
<td>412±50</td>
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</tbody>
</table>

**WEIGHTED MEAN OF ABOVE 7 SAMPLES**

| 3 Bay of Arcachon, France | L-599A | 1952 | 846±42 | -442±h |
| 2,3 Port Jefferson area, Long Island Sound, New York, USA | L-317A | 1954 | 407±75 | -83±75h |

**VALUE USED ON MAP FOR ABOVE SAMPLE**

| 14 Bolinas Bay, California, USA | USGS-248 | 1915±5 | 680±25 | 209±25 |
| 14 Half Moon Bay, California, USA | USGS-280 | 1915±5 | 740±35 | 274±35 |
| 1 Monterey, California, USA | UCLA-149 | 1878 | 566±35 | 269±35 |
| 1 Morro Bay, California, USA | USGS-281 | 1947 | 750±35 | 262±35 |
| 1 Seal Beach, California, USA | UCLA-1033 | 1921 | 553±48 | 80±48 |
| 16 San Diego, California, USA | USGS-430 | 1915±5 | 735±35 | 264±35 |

**WEIGHTED MEAN OF ABOVE 7 SAMPLES**

| 3 Bahama Islands | L-576B | 1950 | 428±42 | -62±42 |

**WEIGHTED MEAN OF ABOVE 8 SAMPLES**

| 3 Bahama Islands | L-576G | 1885±5 | 525±59 | 39±59 |
TABLE 1 (continued)

<table>
<thead>
<tr>
<th>MARINE SHELLS</th>
<th>REFb</th>
<th>REGIONc</th>
<th>SAMPLE #</th>
<th>HISTORICAL AGE (cal AD)d</th>
<th>CONVENTIONAL AGE (14C YRS BP)e</th>
<th>AR (14C YRS BP)f</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Rocks, offshore of Florida Keys, USA</td>
<td>4</td>
<td>24°57'N 80°33'W</td>
<td>(annual coral rings)</td>
<td>&quot;1850&quot; (1800-1900)</td>
<td>518±16</td>
<td>13±16</td>
</tr>
<tr>
<td>Jamaica, B.W.I.</td>
<td>3</td>
<td>18°N 78°W</td>
<td>L-576A</td>
<td>1929-1930</td>
<td>423±42</td>
<td>52±42</td>
</tr>
<tr>
<td>Jamaica, B.W.I.</td>
<td>3</td>
<td>18°N 78°W</td>
<td>L-576F</td>
<td>1984</td>
<td>425±41</td>
<td>62±41</td>
</tr>
</tbody>
</table>

WEIGHTED MEAN OF ABOVE 5 SAMPLES SCATTER ± IN UNWEIGHTED MEAN IS 20 YR

16 | Port Parkar, Costa Rica | UCLA-1254 | 1935 | 695±37 | 216±37 |
16 | Secas Island, Panama (8°N 82°W) | UCLA-1256A | 1934 | 403±51 | 76±51 |
16 | Secas Island, Panama (8°N 82°W) | UCLA-1256B | 1935 | 507±49 | 28±49 |
16 | Santiago Is., Galapagos Is. (0°N 91°W) | UCLA-1255A | 1934 | 538±53 | 60±53 |
16 | Santiago Is., Galapagos Is. (0°N 91°W) | UCLA-1255B | 1934 | 745±82 | 267±82 |
16 | Espanola Is., Galapagos Is. (0°N 90°W) | UCLA-1255C | 1934 | 468±43 | 10±43 |
16 | Santa Cruz Is., Galapagos Islands (0°N 90°W) | UCLA-1255D | 1932 | 443±40 | 34±40 |
16 | Guayaquil, Ecuador (ca. 3°S 80°W) | UCLA-1249A | 1927 | 235±37 | 240±37 |
16 | Guayaquil, Ecuador (ca. 3°S 80°W) | UCLA-1249B | 1927 | 538±45 | 61±45 |

WEIGHTED MEAN OF ABOVE 9 SAMPLES SCATTER ± IN UNWEIGHTED MEAN IS 50 YR

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Minze Stuiver, G W Pearson, and Tom Brazilunas
### TABLE 1 (continued)

<table>
<thead>
<tr>
<th>REFb</th>
<th>REGIONc</th>
<th>SAMPLE #</th>
<th>AGE (cal AD)</th>
<th>SAMPLE 14C AGE</th>
<th>$\Delta R$ (14C YRS BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Inexpressible Island, Antarctica (ca. 74°54'S 163°39'E)</td>
<td>QL-171</td>
<td>1912</td>
<td>1390±40</td>
<td>919±40</td>
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<tr>
<td>15</td>
<td>Inexpressible Island, Antarctica (ca. 74°54'S 163°39'E)</td>
<td>QL-173</td>
<td>1912</td>
<td>1300±50</td>
<td>829±50</td>
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</table>

**NOTES**

- **a** Exceptions are marked.
- **c** Our own estimates of missing coordinates are in parentheses.
- **d** Age refers to calendar year of death. Only pre-1959 samples are listed.
- **e** Conventional radiocarbon age is: taken directly from original listing (references 14, 15, and 17); assumed equivalent to reported "apparent age" (references 6 and 7); calculated from reported $\delta^{14}C$ or $\Delta^{14}C$ (references 1, 13, and 16); calculated from reported $\Delta^{14}C$ after removal of age correction (references 4, 5, 8, 9, and 12); calculated from reported $\delta^{14}C$ after removal of age correction to 1958 (references 2 and 3); or calculated from reported $\Delta^{14}C$ after removal of age correction and fossil fuel correction (reference 10 and Rafter values listed in reference 5).
- **f** Sigma in $\Delta R$ (yr) is minimum error based on reported error in conventional sample $^{14}C$ age.
- **g** Exact year of death is not known.
- **h** Computation is based on the model mixed layer radiocarbon age calculated for AD 1950.