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ACCURATE DATING OF ORGANIC DEPOSITS BY AMS ^{14}C MEASUREMENT OF MACROFOSSILS

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ABSTRACT. We made a comparative study of AMS ^{14}C ages of organic deposits (minerotrophic peats and gyttjas) and macrofossils in order to evaluate the magnitude of a number of sources of error that may be present in bulk sediment samples. The consistency of ^{14}C ages found for coexisting macrofossils suggests that they are unlikely to record disturbances. Some of our gyttja samples yielded an age 0.2–0.6 ka ^{14}C years too old due to hardwater effect. We also found an aging effect in several bulk samples with a high admixture of siliciclastic material; this is attributed to fluvial input of reworked, older organic debris. Rejuvenation of bulk material as a result of root contamination occurs mainly in samples overlain by slowly accumulated deposits, and particularly in samples affected by (sub)recent roots.

INTRODUCTION

Many studies of Late Quaternary paleoenvironments rely heavily on ^{14}C ages of organic deposits. It is widely accepted that ^{14}C ages of bulk organic sediment samples may be affected by a number of error sources. Mook and van de Plassche (1986) give an overview of potential pitfalls in the ^{14}C dating of several materials, including organic deposits. They discuss intrinsic geochemical uncertainties as well as incidental difficulties due to botanical and/or mechanical contamination, which may be especially relevant to organic lake sediments (gyttjas) and minerotrophic peats.

In the Holocene (near-) coastal areas along the southern part of the North Sea, extensive ^{14}C dating of such materials has shown that varying degrees of disturbances can occur. In this area, much attention has focused on the botanical contamination of peats resulting from the vertical penetration of roots. Streif (1971, 1972) studied this effect in samples of *Phragmites* and *Carex* peat by performing comparative dating of two separate fractions (a root/rhizome fraction and a remaining fraction). In most cases, the root/rhizome fraction turned out to be younger; sometimes age differences were as much as 0.5–1 ka ^{14}C years (Streif 1971: Table 5). Van de Plassche (1980, 1982: 57) followed a different approach. He observed an age difference of *ca.* 0.4 ka ^{14}C years between two adjacent samples of fen-wood peat. All roots and rootlets had been removed from the older sample. Although dating results can be improved considerably by manual pretreatment of samples, Scholl and Stuiver (1967: 441) have shown that the time-consuming procedure of removing all suspect fractions is not always successful.

^{14}C ages of strongly clayey, calcareous gyttja-like deposits of Late Holocene residual channels in the eastern Rhine-Meuse delta (eastern Netherlands) were usually >1 ka older than expected on palynological grounds. This was attributed to a hardwater effect (Teunissen 1986: 11–12).

An effect that, in principle, may be present in any sample of minerotrophic peat or gyttja is the fluvial input of older, reworked organic debris. Extensive studies of samples with low organic content from various parts of The Netherlands (Schoute *et al.* 1981; Schoute, Mook & Streurman 1983; Schoute 1984; Roeleveld & Steenbeek, in press) have revealed that, in such materials, this process may lead to substantial increases of ^{14}C ages of alkali residues. However, the frequency

and the magnitude of such problems in peats and gyttjas are not as well documented. Another type of mechanical contamination may result from various kinds of bioturbation after formation of the deposit. This can be expected particularly in oxidized material (*cf.* Mook & van de Plassche 1986: 545).

It has long been recognized that the use of macrofossils for ^{14}C dating can considerably improve results, since they are relatively unlikely to record disturbances such as those described above. Large macrofossils, such as wood stumps, have permitted successful beta-decay dating of organic deposits (*e.g.*, Nelson, Carter & Robinson 1988), but ^{14}C dating of smaller specimens has been a problem because of the general scarcity of material, and thus has been done only on a few occasions (*e.g.*, Vogel & Zagwijn 1967; Shotton 1972).

With the advent of accelerator mass spectrometry (AMS), many ^{14}C studies of organic deposits have benefited from dating specific, well-selected subsamples. These include numerous chemical fractions (*e.g.*, Fowler, Gillespie & Hedges 1986a, b; Lowe *et al.* 1988; Vogel *et al.* 1989), botanical macrofossils (*e.g.*, Lister *et al.* 1984; Andrée *et al.* 1986; MacDonald *et al.* 1987; Nelson, Carter & Robinson 1988; Ammann & Lotter 1989; Cwynar & Watts 1989; van Geel, Coope & van der Hammen 1989; Vogel *et al.* 1989; Peteet *et al.* 1990) and pollen concentrates (Brown *et al.* 1989). Much debate persists about ^{14}C dating chemical fractions of bulk sediment samples, and at present, finding an ideal chemical compound for many different contexts does not seem likely (Fowler, Gillespie & Hedges 1986b). Pollen is a promising tool for dating many types of sediment, possibly including some siliciclastic deposits. However, macrofossils that are available in sufficient quantities, which is usually the case in organic deposits, are probably the most practical elements, in terms of sample preparation time. They are likely to yield accurate dating results, provided that they have been formed and deposited *in situ*. If macrofossils are allogenic, it is essential that they have not been eroded from older geological strata or soils.

A few AMS studies have concentrated more systematically on the age relationship between terrestrial macrofossils, gyttjas and carbonates (Andrée *et al.* 1986) or terrestrial macrofossils and aquatic mosses (MacDonald *et al.* 1987), especially for the purpose of detecting hardwater effects. Comparable investigations are also needed for the frequency and magnitude of disturbing effects in peats. Thus, we have made a systematic comparison between AMS ^{14}C ages of bulk samples of different types of minerotrophic peat or gyttja and macrofossils from the same stratigraphic level. Such studies are necessary not only to establish when AMS ^{14}C dating of macrofossils is preferable to (conventional) dating of bulk samples, but also to reevaluate previously published ^{14}C ages of organic bulk material. Törnqvist, de Jong and van der Borg (1990) reported the first results of this project.

Methods

Samples were collected from cores of the Leerdam-Gorkum area in the Rhine-Meuse delta (central Netherlands). All samples were taken from either the top or the base of an organic bed, directly underlying or overlying fluvial clay, respectively. As in many (near-) coastal areas, these organic beds consist mainly of wood (*Alnus*) and herbaceous peat (mainly *Phragmites*), whereas organic lake sediments (gyttja) occur locally. For samples from bases of organic beds, we attempted, wherever possible, to select samples that were underlying a similar type of material.

Sixteen samples, 1–5 cm thick, were split into 1–2 bulk subsamples (when a second bulk sample was used, we removed all macroscopically visible roots) and 1–3 macrofossil subsamples. After removal of the outer zone of the core, the bulk material was sampled from the central part. The remainder was sieved over a 500-μm screen. All identifiable macrofossils (fruits, seeds, cones,

wood, fragments of beetles, *etc.*) were picked out using a binocular microscope, and were then carefully cleaned and stored in distilled water acidified to pH < 2 with HCl at 2–3°C before further preparation.

In the peat samples, we selected the macrofossils or macrofossil assemblages most likely to have originated locally. As far as possible, we selected the best-preserved specimens (*e.g.*, fruits with undamaged pericarps), and preferably those available in large quantities and bound ecologically and/or geologically to the type of sediment within which they occurred (*cf.* Nelson, Carter & Robinson 1988). We could not always find enough material to satisfy these criteria. For gyttja samples, we took a different approach. Because the ^{14}C activity of autochthonous (aquatic) plants may be affected by hard water in the same way as lake sediments (Deevey *et al.* 1954; Håkansson 1979; MacDonald *et al.* 1987; Marčenko *et al.* 1989), we also used terrestrial (allochthonous) macrofossils.

Samples were chemically pretreated using standard procedures (Mook & Streurman 1983) and prepared for measurement at the AMS facility of the University of Utrecht (van der Borg *et al.* 1987). Most samples were treated with 4% HCl (50°C), 0.5% NaOH (20°C) and 4% HCl (20°C). Some of the macrofossil samples were given a less rigorous treatment (2% HCl at 20°C; see Table 1). After oxidation, the CO_2 was reduced to graphite (0.3–3.0 mg C) at 620°C, using H_2 and Fe powder as a catalyst. Part of the CO_2 gas was used for $\delta^{13}C$ measurement with gas mass spectrometry at the Institute of Earth Sciences, University of Utrecht.

Only the fulvic acids were removed from the macrofossil samples that had been treated only with acid. Thus, some humic acids may remain, but we believe that these do not affect the dating results, because serious age differences between alkali extracts and alkali residues of minerotrophic peat from (near-) coastal areas of The Netherlands have never been observed (Schoute 1984: Tables 8, 28; Berendsen 1986: 54; Roeleveld & Steenbeek, in press). Further, we found that some of our macrofossil samples contained only *ca.* 15% humic acids.

RESULTS AND DISCUSSION

Data Presentation

Table 1 shows all the ^{14}C ages and related information. In our earlier report (Törnqvist, de Jong & van der Borg 1990), subsamples were compared in terms of age differences expressed as conventional ^{14}C years. Figure 1 illustrates a similar comparison of subsamples. Assessing ^{14}C age differences among samples can be problematic because of the non-linear relationship between the ^{14}C and calendar time scale. Thus, we converted our ^{14}C ages to calendar age ranges according to the calibration program of van der Plicht and Mook (1989). For bulk and multi-macrofossil samples, sample time width should be assessed in order to determine whether smoothing of the calibration curve is necessary before the samples are calibrated (*cf.* Mook 1983). In view of the generally low mean time width of these samples, estimated at <40 yr, all ^{14}C ages were calibrated without further smoothing (in fact, the calibration curve is already averaged over 20-yr intervals). We used the one standard deviation (1 σ) confidence interval, calculated from the probability distribution of the calibration. We chose an integration step of four (see van der Plicht & Mook 1989: 807) in order to arrive at values rounded to five years.

Figure 2 shows the resulting comparison of calendar ages for all the samples. Only in the case of Samples 8 and 10, calibration leads to different (smaller) age differences between subsamples than conventional ^{14}C results. This suggests that, in a few cases, age differences are (at least partly) caused by ^{14}C variations and, thus, are artificial.

TABLE 1. ^{14}C Ages of Organic Bulk Sediment Samples and Macrofossils

Sample no.	Material	Chemical pretreatment*	Weight (mg C)	$\delta^{13}C_{PDB}$ (‰)	^{14}C age (yr BP)	UtC-no.
1a	*Alnus* peat	AAA	2.05	−31.0	3380 ± 60	1479
1b	1 *Sparganium erectum* fruit	AAA	0.70	−29.2	3630 ± 40	1410
2a	*Alnus* peat	AAA	1.99	−29.2	3160 ± 90	1138
2b	3 *Alnus glutinosa* nuts, 2 *Oenanthe aquatica* mericarps	A	1.13	−28.2	3190 ± 120	1139
2c	Fragment of *Alnus glutinosa* cone	AAA	1.61	−27.4	3080 ± 90	1140
3a	*Alnus* peat	AAA	2.41	−29.7	3310 ± 80	1133
3b	1 *Sparganium erectum* fruit	A	2.02	−29.4	3250 ± 70	1134
3c	6 *Oenanthe aquatica* mericarps	A	1.98	−28.5	3070 ± 90	1135
4a	Slightly clayey *Alnus* peat	AAA	1.58	−28.9	3170 ± 80	1131
4b	7 *Oenanthe aquatica* mericarps	A	1.44	−28.2	3250 ± 70	1132
5a	Strongly clayey *Alnus* peat	AAA	2.17	−28.2	4580 ± 110	1141
5b	20 *Alisma plantago-aquatica* fruits	A	0.45	−27.5**	4740 ± 160	1142
6a	Strongly clayey *Alnus* peat	AAA	1.30	−29.5	1900 ± 50	1480
6b	Strongly clayey *Alnus* peat (living roots removed)	AAA	1.13	−29.0	2150 ± 40	1425
6c	10 *Oenanthe aquatica* mericarps	AAA	1.42	−29.9	1880 ± 30	1426
6d	Fragment of *cf. Alnus* wood	AAA	1.62	−27.0	1920 ± 70	1427
7a	Strongly clayey *Alnus* peat	AAA	1.44	−29.1	2290 ± 60	1481
7b	Fragment of *cf. Alnus* wood	AAA	1.14	−29.6	2210 ± 40	1482
8a	*Phragmites* peat	AAA	2.84	−28.1	5090 ± 50	1295
8b	*Phragmites* peat (roots removed)	AAA	2.99	−28.3	4940 ± 70	1296
8c	Fragments of Coleoptera (*Plateumaris consimilis, cf. Donacia*) and various terrestrial botanical macrofossils (mainly *Carex* spp. nuts)	AAA	0.39	−27.5**	4990 ± 70	1408
9a	*Phragmites* peat	AAA	1.49	−28.8	4670 ± 80	1128
9b	9 *Humulus lupulus* fruits	A	0.79	−25.9	4670 ± 130	1129
9c	Fragment of *Alnus glutinosa* cone	AAA	1.70	−26.1	4500 ± 80	1130
10a	Slightly clayey *Phragmites* peat	AAA	0.44	−27.5**	5620 ± 50	1556
10b	10 *Carex* sp. nuts	AAA	0.32	−27.5**	5360 ± 50	1557

TABLE 1. (Continued)

Sample no.	Material	Chemical pretreatment*	Weight (mg C)	$\delta^{13}C_{PDB}$ (‰)	^{14}C age (yr BP)	UtC-no.
11a	Strongly clayey *Phragmites* peat	AAA	2.54	−28.7	5110 ± 90	1136
11b	3 *Scirpus lacustris* nuts	A	1.30	−25.1	5240 ± 90	1137
11c	3 *Scirpus lacustris* nuts	AAA	1.02	−26.5	5300 ± 70	1299
12a	Strongly clayey *Phragmites* peat	AAA	1.04	−29.0	5320 ± 60	1294
12b	Fragments of Coleoptera (mainly *Donacia cf. dentata*) and various terrestrial botanical macrofossils (mainly *Carex* sp. nuts)	AAA	0.87	−24.9	5230 ± 50	1407
13a	Strongly clayey *Phragmites* peat	AAA	3.09	−28.9	5440 ± 50	1297
13b	2 *Scirpus lacustris* nuts	AAA	1.15	−25.2	5240 ± 70	1397
13c	Fragments of Coleoptera (mainly *Donacia* spp., also remains of Carabidae)	AAA	0.59	−27.5**	5330 ± 70	1396
14a	Slightly calcareous, brownish yellow gyttja	AAA	1.81	−26.8	4460 ± 70	1125
14b	1 *Nuphar lutea* seed	A	1.46	−30.4	4470 ± 70	1126
14c	4 *Potamogeton* sp. fruits	A	0.88	−27.9	4500 ± 140	1127
14d	5 *Alisma plantago-aquatica* fruits, 3 *Oenanthe aquatica* mericarps, 3 *Carex* sp. nuts, 1 *Rumex* sp. fruit, 1 *Solanum nigrum* seed	AAA	0.73	−28.0	4240 ± 50	1409
15a	Brownish yellow gyttja	AAA	0.70	−30.5	4570 ± 120	1298
15b	2 *Nymphaea alba* seeds	AAA	0.60	−27.5**	3970 ± 60	1405
15c	1 *Euphorbia palustris* seed	AAA	2.29	−24.5	4030 ± 30	1406
16a	Slightly calcareous, strongly clayey, slightly sandy, grayish brown gyttja	AAA	2.34	−29.5	5490 ± 100†	1143
16b	2 *Scirpus lacustris* nuts	A	1.35	−25.6	5100 ± 110	1144
16c	2 *Scirpus lacustris* nuts	AAA	0.67	−25.4	4980 ± 130	1300

*AAA = acid–alkali–acid; A = acid

**Estimated

†Previously published age (Törnqvist, de Jong & van der Borg 1990) was modified because of an additional measurement.

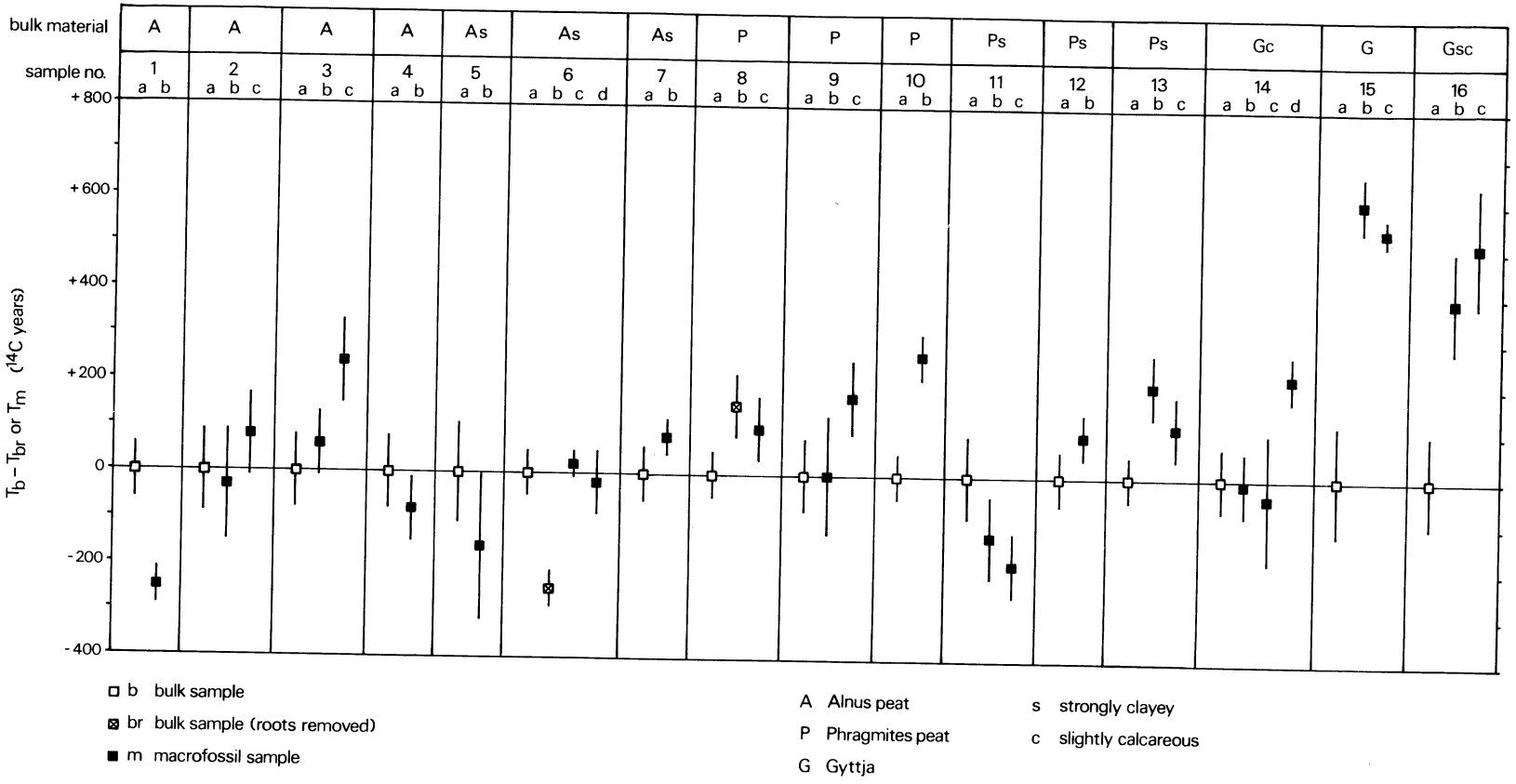

Fig. 1. Age difference between bulk and macrofossil subsamples for 16 samples of minerotrophic peat or gyttja, expressed in conventional ^{14}C years. Bars indicate the 1 σ confidence interval. Bulk sediment ages are normalized to zero. Positive and negative macrofossil ages indicate aging and rejuvenating effects on the corresponding bulk material, respectively.

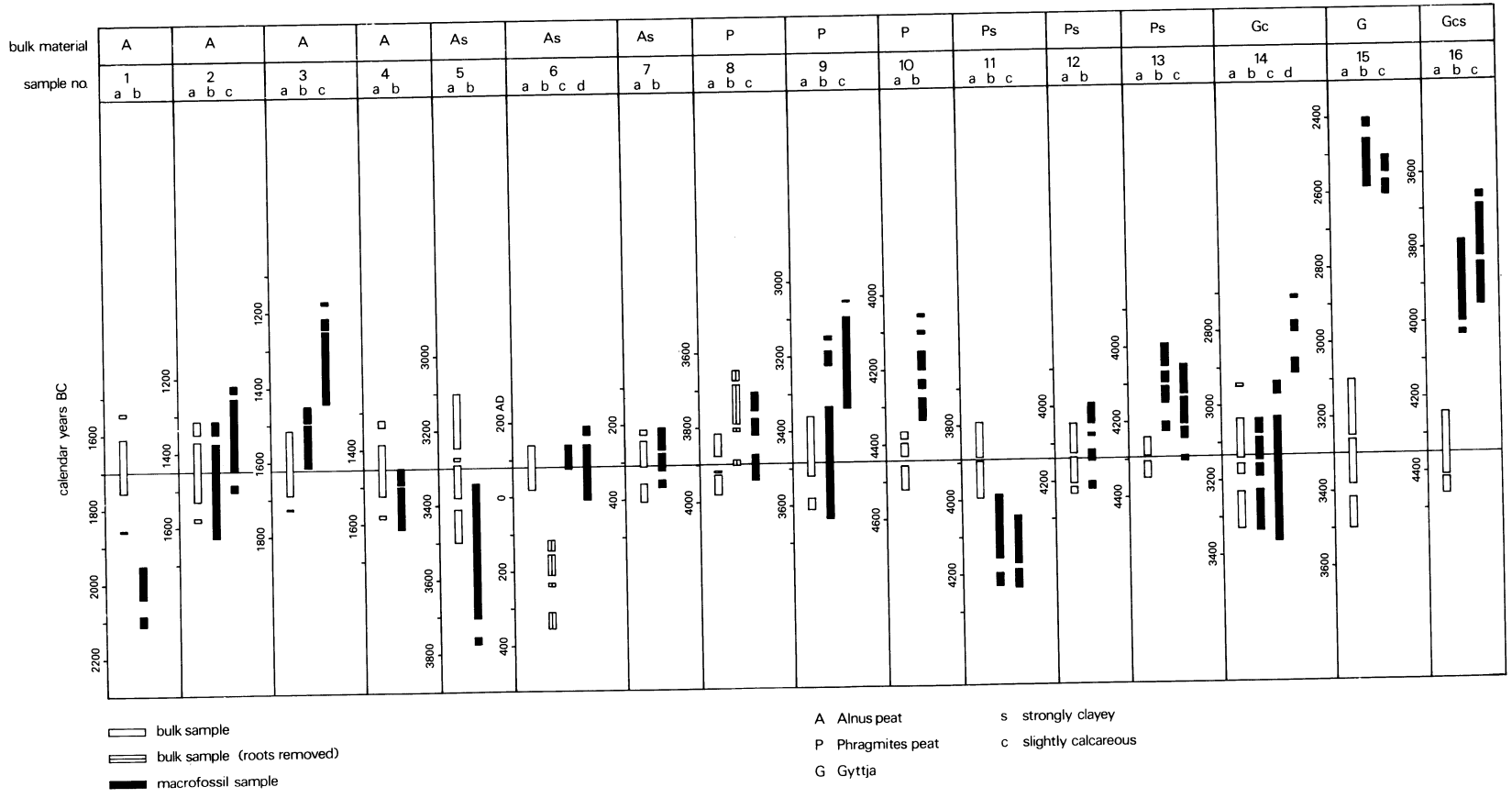

Fig. 2. Age difference between bulk and macrofossil subsamples for 16 samples of minerotrophic peat or gyttja. ^{14}C ages have been converted to calendar ages according to van der Plicht and Mook (1989). Bars indicate the (usually discontinuous) 1 σ confidence interval. Bulk sediment ages are normalized to a reference level (= mean of upper and lower limit of the 1-σ confidence interval). Positive and negative macrofossil ages indicate aging and rejuvenating effects on the corresponding bulk material, respectively.

Comparison of ^{14}C Ages of Coexisting Macrofossils

Two or more macrofossil subsamples were dated in nine samples (Figs. 1, 2). In most of these cases, one of the macrofossil samples consisted of one single specimen. This allows for the proper evaluation of the consistency of ^{14}C ages of coexisting macrofossils, since similar dating results can be expected on statistical grounds in the case of macrofossil assemblages composed of a large number of individuals. Except for Sample 14 (where some of the macrofossil ages are affected by hard water), there is no reason to assume a real age difference between coexisting macrofossils. Although much more evidence is needed to make a generalization, our data suggest that there is little risk of using reworked (and, hence, too old) macrofossils for ^{14}C dating, at least when such elements are selected critically.

Hardwater Effect

Relatively large age differences between bulk material and (terrestrial) macrofossils are found in Samples 14 and 15 (Figs. 1, 2). The typical yellow color of these gyttja samples is probably caused by siderite (P. Cleveringa, personal communication 1991). For both samples, the observed age difference (0.2–0.6 ka) can be ascribed to hardwater effect, which confirms once more that terrestrial macrofossils are needed for useful ^{14}C ages of gyttjas (*cf.* Shotton 1972; Andrée *et al.* 1986). Samples 14 and 15, both collected from small (10-m wide, 2-m deep) residual channels, further underscore the view expressed by Teunissen (1986: 11–12) that gyttja-like material from such environments is likely to yield results that are too old. Although flowing extremely gently, the steady supply of river water (with dissolved $CaCO_3$ from the Rhine catchment area) will have prevented complete mixing of CO_2 between water and atmosphere, thus preserving a differential $^{14}C/^{12}C$ ratio.

We also investigated macrofossils of aquatic plants in these samples. The results show that *Potamogeton* sp. fruits (Table 1: 14c) fully record the hardwater effect; this is not surprising, considering that most plants belonging to this genus are submerged. Most interesting are the results for seeds of *Nuphar lutea* (14b) and *Nymphaea alba* (15b). According to Smits *et al.* (1988: 57), the floating leaves of full-grown nymphaeids have access to atmospheric CO_2. On the other hand, measurements presented by Olsson (1983: Fig. 2) indicate that floating plants may exhibit significant ^{14}C depletion. However, our data suggest a marked difference between the two species, as the *Nuphar lutea* seed reveals an age similar to that of the bulk material. The result obtained for *Nymphaea alba* seeds corresponds neatly to that of terrestrial material. Although *Nuphar lutea* is known to have more submerged leaves than *Nymphaea alba* (G. van der Velde, personal communication 1991), which may be related to the discrepancy observed here, we do not yet have a satisfying explanation for this phenomenon.

Mechanical Contamination

An aging effect also can be observed in the bulk material of Samples 6, 10, 13 and 16. In Sample 6, this holds only for bulk Subsample 6b, from which living roots were removed. Although age differences are not statistically significant in all cases, it is striking that this effect is found especially in samples with a high siliciclastic (clayey, sometimes also sandy) content. It is very probable that fluvial processes resulted not only in an admixture of siliciclastic material, but also in the deposition of reworked, fine-grained organic debris. In view of the sand content of Sample 16 (gyttja), we believe that, here too, mechanical contamination, rather than hard water, is responsible for the aging of the bulk material. This supposition is also based on the fact that this sediment was formed in a flood basin with shallow, stagnant water, where there was probably a rapid mixing of CO_2 between water and atmosphere.

Aging effects resulting from fluvial transport of organic material have been reported earlier (Blong & Gillespie 1978), and are a problem mainly in sediments of low organic content (Olsson 1979). In The Netherlands, it has been demonstrated that the humin fraction of vegetation horizons (paleosols) and humic clays is usually too old due to this effect (Schoute *et al.* 1981; Schoute, Mook & Streurman 1983; Schoute 1984; Roeleveld & Steenbeek, in press). The extensive comparison of ^{14}C ages of alkali residues and alkali extracts given by Roeleveld and Steenbeek (in press) indicates that the humin fraction of strongly humic clays and (clayey or non-clayey) peats will normally yield reliable ^{14}C ages. However, our data suggest that strongly clayey peats or gyttjas also may be affected by mechanical contamination. In our study area, very thick organic beds are prone to fluvial erosion, and hence, reworking and redeposition of organic material. Using Olsson's (1974: Fig. 1) calculations, we can estimate roughly that contamination of our samples with material from these organic beds ranges from *ca.* 10% (Sample 6) to *ca.* 30% (Sample 16). Of course, these values may be lower, if older organic material is also brought into the area of study. However, we do not expect such material to make a major contribution.

We see no evidence for mechanical contamination resulting from bioturbation, since Sample 6, which consists of oxidized peat, revealed an excellent agreement of the age of two coexisting macrofossil samples.

Botanical Contamination

Root contamination can be expected particularly in samples consisting of and overlain by *Phragmites* peat, as well as in samples (potentially) affected by (sub)recent roots. Although Streif (1971: Table 5) found very large age differences between root/rhizome and residual fractions in samples assumed to have accumulated slowly, it is uncertain to what extent this process will affect samples from which roots have not been removed. In Samples 6 and 8, we dated a second bulk sample from which roots (in Sample 6b, only living roots) had been removed. This had no effect in Sample 8. In Sample 6, which was included in this study because of its contamination by recent roots (even live worms were encountered under the binocular microscope!), removal of living roots considerably increased the age of the peat. On the other hand, the corresponding macrofossil samples revealed an age similar to that of the unpretreated bulk material, indicating that botanical contamination may be counterbalanced by mechanical contamination. We do not rule out the possibility that this is also the case in other samples. Contamination by recent roots is also likely for the bulk material of Sample 1. Only Samples 1 and 6 were collected at a depth of <1 m. Only Sample 11 shows slight rejuvenation of bulk material due to vertical penetration of *Phragmites* roots.

As already stated by Streif (1971, 1972) and van de Plassche (1980, 1982), the effect of root contamination is highly dependent on accumulation rate. The rather high accumulation rate for most of our *Phragmites* peat samples (on the order of 5–15 cm per century) seems to be a plausible explanation for the small impact of this effect. The large age difference due to root contamination found in fen-wood peat by van de Plassche (1980, 1982: 57) can be satisfactorily explained by different local conditions at his sampling site. The age of the top of the peat layer above his samples is estimated at *ca.* AD 1000 (O. van de Plassche, personal communication 1991), which yields a mean accumulation rate of only *ca.* 1 cm per century. The mean accumulation rate of the sediments overlying our Samples 1 and 6 is estimated at 2.5 and 4.5 cm per century, respectively. This clearly confirms the general opinion of a close association between root contamination and accumulation rate.

For older organic beds (> *ca.* 10 ka BP) occurring fairly close to the surface, the extremely low accumulation rate (mainly because of large hiatuses) can give rise to very large rejuvenating effects

resulting from (sub)recent root intrusion. Vogel and Zagwijn (1967: 67) demonstrated rejuvenation of bulk material by more than 10 ka ^{14}C years due to this effect.

Conclusions

1. Internal consistency of ^{14}C ages of coexisting macrofossils from organic deposits justifies their utility for obtaining accurate dating results. We believe that a critical selection of macrofossils for ^{14}C dating can provide a strong association with the phenomenon of study (*cf.* Vogel *et al.* 1989), and can minimize the risk of using reworked, older specimens.
2. Significantly younger ages of terrestrial macrofossils demonstrates hardwater effect in some of our gyttja samples. Dating of macrofossils of aquatic plants should be avoided in cases where hardwater effects are likely to be present, because results are variable and not yet fully understood.
3. Mechanical contamination is a problem not only in sediments with low organic content, such as humic clays and vegetation horizons, but also in strongly clayey peats or gyttjas occurring in areas where large-scale reworking and redeposition of older organic beds are likely.
4. Although, in many cases, botanical contamination of peat cannot be ruled out, we believe it is less problematic than previously supposed. However, samples that are not likely to be mechanically contaminated (especially peats with a low content of siliciclastic material) overlain by slowly accumulating (<5 cm per century) peats formed by plants with deeply penetrating roots and rhizomes (*e.g.*, *Phragmites*) are likely to be rejuvenated by root contamination. The same holds for samples (especially older ones) affected by (sub)recent roots.
5. For gyttjas and strongly clayey samples, special care should be taken in interpreting the numerous available bulk ^{14}C ages of organic deposits. Further, materials from sites with a low accumulation rate should be considered suspect. For rapidly (>5 cm per century) accumulating pure peats, however, bulk ^{14}C ages can be considered more or less useful. In spite of this, it is clear that when highly accurate dating of organic deposits is required, AMS ^{14}C dating of macrofossils is a powerful tool.

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