19. RADIOCARBON DATING

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INTRODUCTION

Radiocarbon dating of marine deposits, irrespective of whether they consist of shells or gyttja, is always hazardous because of contamination by older allochthonous material (Olsson 1982). Peat deposits mainly consist of autochthonous material although intrusive elements such as roots may cause the ages to appear too late (Olsson and Florin 1980). Autochthonous marine shells and gyttja will always appear too old because of the reservoir age, although a fair estimate of this can be made. It is here estimated as 330 ± 20 years (Olsson 1980). Similarly, lakes usually have a reservoir age but unfortunately this varies from lake to lake (Olsson 1982) and often with time (Geyh *et al.* 1970). The reservoir age of the lake may derive from dissolved old carbonate (Deevey *et al.* 1954), but may also be observed in soft-water lakes, being there due to supply of aged water. Although the conditions vary from one lake to another the general rule is that the risk of errors, causing the ages to appear too old, increases as the amount of carbon decreases. Some old carbonaceous material can easily be deposited together with the minerogenic material (Hörnsten and Olsson 1964, Olsson 1972, 1973, 1978, 1979). Thus every result must be evaluated, taking the origin of the sample into consideration in order to avoid mistaken association with the boundary or any other level. Apparently the fraction soluble in NaOH is more reliable than the insoluble fraction (Olsson 1973, 1979). A re-evaluation of many ^{14}C dates from Finland was made by Donner and Jungner (1973, 1974).

Earlier Mörner (1976) summarized several dates for the determination of the boundary or levels below or above that boundary. The samples used are usually clay, dy or gyttja. The dates from core B 873 derive from samples pretreated with HCl. The same applies to Näckrosdammen and at least some other samples. The pretreatment method is not described by Mörner. Each of his dates should therefore be regarded as, most probably, too early for the respective level partly because of contamination *in situ,* partly because of the reservoir effekt.

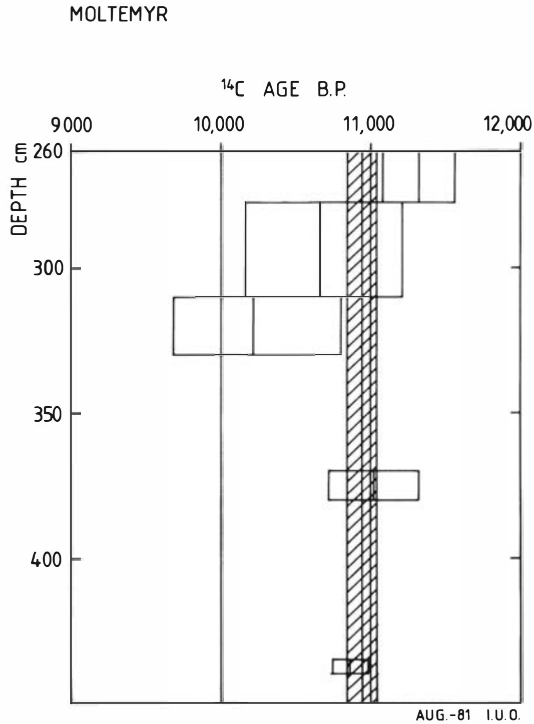

Fig. 19:1. The radiocarbon ages of shell samples from Moltemyr. The values are not corrected for the reservoir age.

THE PRESENT DATINGS

General – Samples such as peat, gyttja and clay were all treated with acid and sodium hydroxide to remove carbonate and to separate each sample into two fractions – one soluble (SOL) and one insoluble (INS) – as described by Olsson (1979). The shell samples were too small to allow the normal treatment to separate them into two or more fractions by leaching with acid after removal of the outer parts.

The radiocarbon ages are calculated using the half-life 5 570 years and given B.P. (before AD 1950). All calculations include a normalization of the sample activities to $\delta^{13}C$ = –25 o/oo in the PDB scale. The international standard is used, *i.e.* 95% of the activity of the NBS oxalic acid in 1950 when this has a $\delta^{13}C$ value of –19 o/oo in the PDB scale. The uncertainties given are $\pm 1\sigma$. All estimated uncertainties connected with the activity measurements are included insofar as is possible (Olsson 1966).

Several samples were too small to allow measurements without dilution

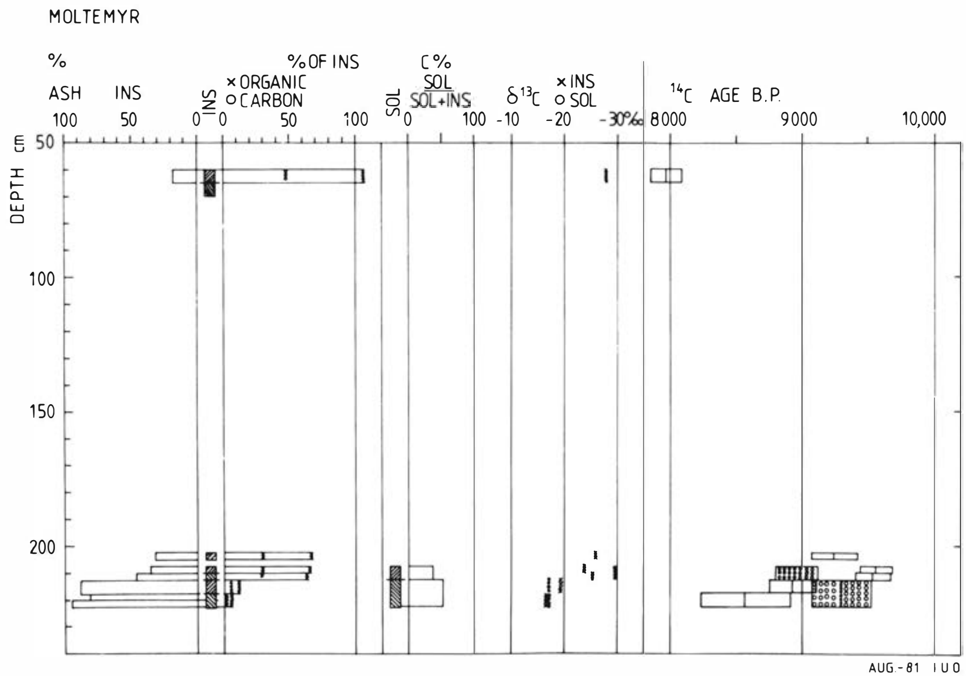

Fig. 19:2. The radiocarbon ages, $\delta^{13}C$ values, carbon content and ash of the INS-fraction, relation between the SOL- and INS-fractions, and measured organic samples from Moltemyr, not corrected for the reservoir age.

with inactive carbon. Many of these samples were measured repeatedly during a total time exceeding the normal period to reduce the statistical uncertainty. Two very small shell samples were sent as carbon dioxide to the Trondheim laboratory, measured there by Gulliksen and later returned to Uppsala where they were diluted or further diluted, respectively, before remeasurement.

In the diagrams both the ash after combustion and the content of carbon, estimated from the yield at the combustions, are given. The organic content is then estimated from the carbon content. The figures for these three components are to be regarded as estimates to guide the evaluation of the accuracy of the dates.

Samples are still submitted in close collaboration with others in the team. This paper is thus a working report giving the results as complete on Aug. 10th 1981.

Some shell samples are stored in sealed evacuated glass ampoules for later ^{14}C dating using the accelerator technique for the ^{14}C determination.

TABLE 19:1. Radiocarbon ages of the samples dated for the Pleistocene-Holocene boundary project. (Aug. 10th, 1981).

Site	Material	Dating no.	Level	$\delta^{13}C$ o/oo	^{14}C age B.P. ($\pm 1\sigma$)
Moltemyr	Shell fragments	U-4420	440–435	−0.9	10860 ± 120
		U-4419	380–370	−2.8	11020 ± 300
		U-4418	330–310	−0.3[a]	$10220\pm^{580}_{540}$
		U-4417	310–277.5	−0.3	$10660\pm^{560}_{500}$
		U-4416	277.5–265	−0.2	11320 ± 240
	Mean	–	–		10940 ± 100
	Organic INS	U-4414	222.5–217.5	−16.6	8570 ± 340
		U-4413	217.5–212.5	−19.3	8930 ± 180
		U-4411	212.5–210	−25.5	9530 ± 130
		U-4410	210–207.5	−23.9	$9550\pm^{130}_{120}$
		U-4409	205–202.5	−26.0	$9240\pm^{180}_{170}$
		U-4425	65–60	−27.7	7970 ± 120
	Organic SOL	U-4415	222.5–212.5	−17.2	$9440\pm^{300}_{290}$
		U-4412	212.5–207.5	−29.6	9020 ± 170
Rörmyr	Organic INS	U-4428	745–742.5	−20.1	9850 ± 240
		U-4427	742.5–740	−19.9	9730 ± 230
Solberga	Shell fragments	T-2982	2620+2624	−2.3	10610 ± 300
		U-4407	2620+2624	−2.3	$10800\pm^{600}_{540}$
		U-4350	2700–2675 2665–2655	−1.7	$11520\pm^{440}_{380}$
		U-4349	2655–2635 2625–2605	−2.2	11020 ± 340
		T-2983	1900–1800	−3.7	9170 ± 400
		U-4408	1900–1800	−3.7	$9160\pm^{1460}_{1240}$
Vägen	Organic INS	U-4422	293–289	−19.7	9670 ± 140
		U-4421	270–267.5	−28.5	9150 ± 140
		U-4424	170–160	−27.8	7410 ± 120
	Organic SOL	U-4423	293–289	−22.9	9750 ± 130

[a] $\delta^{13}C$ assumed.

Moltemyr – Five shell samples were dated from levels between 440 and 265 cm down. Each sample derives from 20 cm or less of the core, but chosen to represent not too long a time. Consequently all but one sample had to be diluted. The samples did not show any trend in radiocarbon age as a function of depth, and there is hardly any significant difference between them (Fig. 19:1). The mean value is about 10 600 radiocarbon years after subtraction of the reservoir age (Table 19:1). In all probability the shells represent old assemblages redeposited at Moltemyr, as Fries suggested earlier (1951). If shells derive from a shell bank it must be remembered that different species may yield ages within a range of thousands of years (Eriksson and Olsson 1967). Donner and Jungner (1980) reviewed various sites and reported the risk of contamination by redeposition. The species

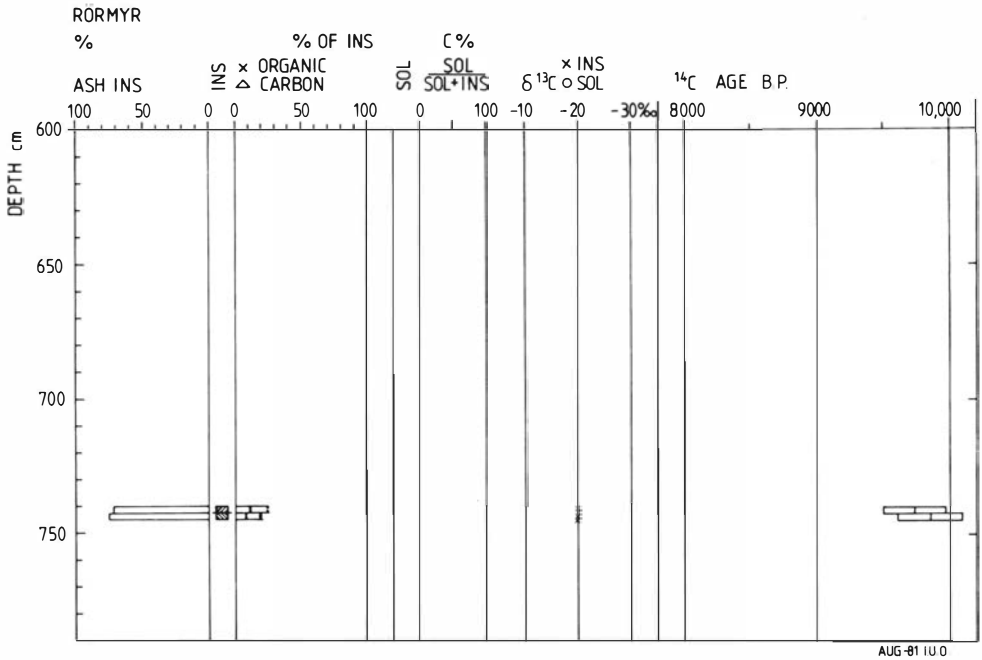

Fig. 19:3. The radiocarbon ages, $\delta^{13}C$ values, carbon content and ash of the INS-fraction, and measured samples from Rörmyr, not corrected for the reservoir age.

selected for dating may yield ages indicating when the living conditions were favourable rather than when the shells were finally deposited. Shells in the neighbourhood of Moltemyr, at Ormdal, were dated as St-5377 at 11 090 ± 180 ^{14}C years B.P. (C. Fredén, pers. comm.).

The organic carbon was first dated for the levels between 222.5 and 202.5 cm down (Fig. 19:2). Five samples were dated as INS-fractions whereas two – only below 207.5 cm down – were dated as SOL-fractions. The $\delta^{13}C$ values indicate different origins below and above 212.5 cm. The two samples dated as INS-fractions below 212.5 cm appeared younger than the three samples above this level. The two SOL-fractions, being contemporary, appear to have the same age as the INS-fractions below 212.5 cm. Taken together these four dates indicate a time slightly earlier than 9 000 years B.P. With a correction for any reservoir age the result would indicate a slightly later time. The samples above 212.5 cm were apparently contaminated *in situ*.

Later on samples were chosen to date levels close to A°. The first sample, 60 to 65 cm down, was about 8 000 radiocarbon years old (Table 19:1).

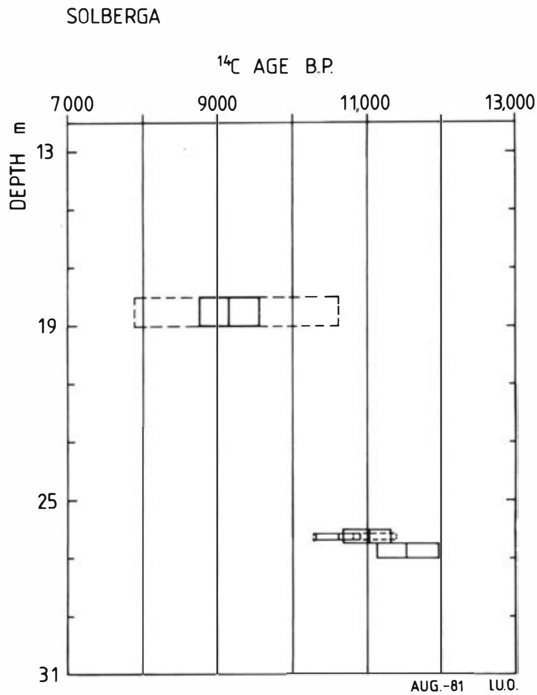

Fig. 19:4. The radiocarbon ages of shell samples from Solberga measured in Trondheim and Uppsala. The values are not corrected for the reservoir age.

Rörmyr – Two samples, clay gyttja, 740 to 745 cm down in the core, Bp 2, were dated as INS-fractions (Table 19:1). The corresponding SOL-fractions were combined in a single sample which is dated but not yet finally calculated. The INS-fractions indicate a time later than 10 000 years B.P. (Fig. 19:3).

Solberga – Shell fragments were dated from rather long sections (Fig. 19:4). The first two samples from 2700 to 2655 and 2655 to 2605 cm respectively were dated at 11 520 $\pm\,^{440}_{380}$ and 11 020 ± 340 ^{14}C years B.P., before subtraction of the reservoir age. Another sample, from the two levels 2620 and 2624 cm, was dated in Trondheim and Uppsala at *c.* 10 600 ^{14}C years B.P. (Table 19:1). Yet another sample was dated by both laboratories, 1900 to 1800 cm, at *c.* 9 200 ^{14}C years B.P. The equipment in Trondheim allows smaller samples to be dated – with acceptable statistical uncertainty – than are feasible in Uppsala. The preparations were performed in Uppsala.

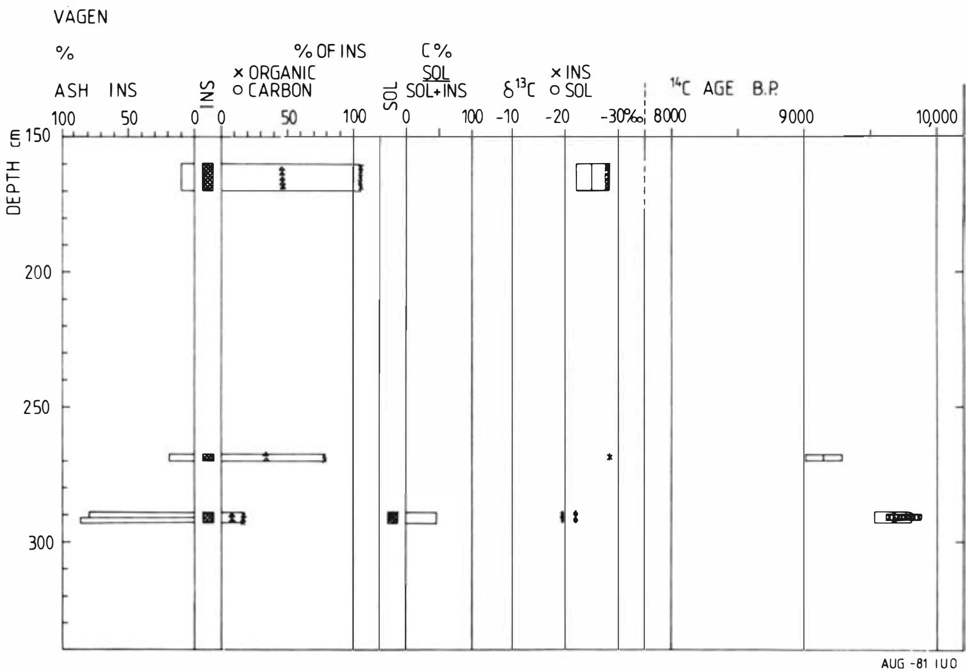

Fig. 19:5. The radiocarbon ages, $\delta^{13}C$ values, carbon content and ash of the INS-fraction, relation between the SOL- and INS-fractions, and measured samples from Vägen, not corrected for the reservoir age.

Vägen – Two samples, one consisting of clay gyttja above the assumed boundary Younger Dryas/Preboreal, and one of *Equisetum* peat at the Preboreal *Betula* maximum, were dated – the deepest as two fractions, INS and SOL, (Fig. 19:5). The $\delta^{13}C$ values confirm their different origins. The fractions of the deepest sample are *c.* 9 700 ^{14}C years old. The, seemingly, younger INS-fraction is not significantly younger than the SOL-fraction. The peat sample (267.5 to 270 cm down) was dated at 9 150 ± 140 years. Further samples close to the assumed boundary were ^{14}C measured but the results are not yet calculated. One peat sample at a level close to A° is ready (Table 19:1).

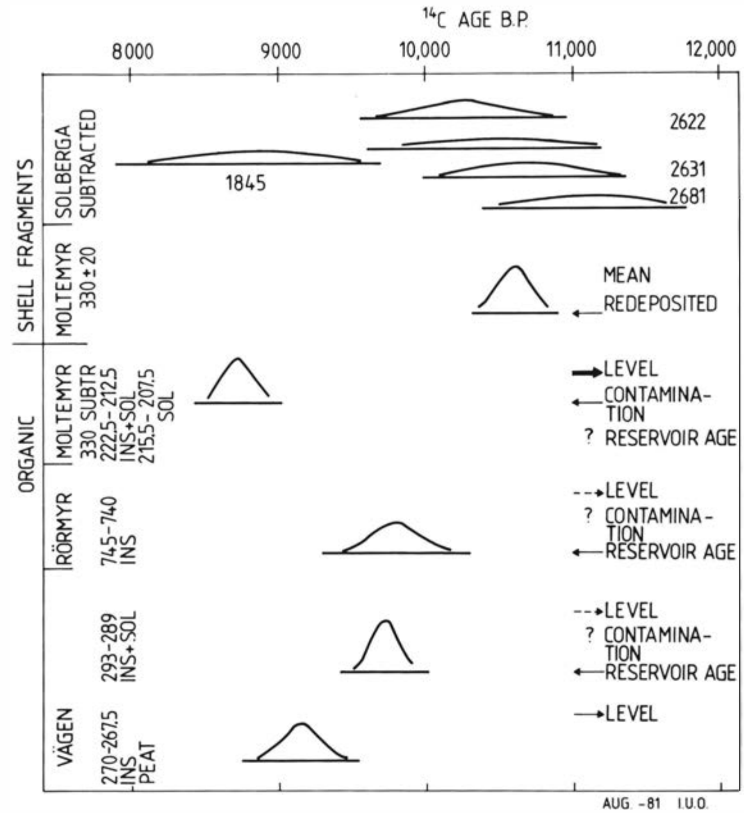

Fig. 19:6. Selected samples, which may yield upper and lower limits for the assumed boundary. A dashed arrow indicates a small possible correction, a normal arrow that a correction is needed and a heavy arrow that the correction is presumably large. A question-mark indicates that it is difficult to make predictions about the corrections or error.

DISCUSSION

Because of redeposition shells may be older than the sediment at the level at which they are found. This was obvious in the case of Moltemyr. The deepest shell layer dated is the only one which we cannot exclude *a priori.* This suggests an upper age limit for the depth 440 to 435 cm. This limit is 10 610 ± 110 ^{14} years B.P. after subtraction of the reservoir age (Fig. 19:6). The deepest Solberga samples, too, should give an upper limit or correct results for the depth 27 to 26 m (~11 000 ^{14}C years B.P. uncorrected for the reservoir age). The date for the highest Solberga shells (19 to 18 m) of 9 170 ± 400 ^{14}C years B.P. uncorrected for reservoir age may be correct or too *early.*

The least squares method yields an age of 9 260 ± 370 ^{14}C years B.P., uncorrected for reservoir age, for the level 19.0 m at Solberga. Thus the upper limit to be used for the 19.3 m level is 9 000 ± 300 ^{14}C years B.P., *assuming* a constant accumulation rate. Such an assumption is not justified from the geological evidence. The uncertainty must be increased. The level 26.22 m, dated at about 10 300 ± 300 ^{14}C years B.P. (corrected for reservoir age), is, however, younger than expected from the assumption of a constant accumulation rate. The difference is insignificant. The 18.45 m level (19–18 m), dated at 8 840 ± 400 ^{14}C years B.P., after correction for reservoir age, yields a low limit for the boundary zone.

The samples dated as organic fractions may yield too early results because of contamination. The reservoir age is not always subtracted since no figure for the freshwater is known. But its subtraction as regards the early Moltemyr sample is possible. The final age here may be several hundred years younger for this level above the boundary.

The Rörmyr 2 samples (745–740 cm) taken just above the tentative Pleistocene/Holocene boundary (~7.5 m) are probably younger than the calculated 8 790 ± 170 ^{14}C years B.P., because of the reservoir age. It is too early to define the risk of contamination since the result from the SOL-fraction is not yet available.

The samples from Vägen may give some guidance. The tentative Pleistocene/Holocene boundary occurs here at 295 cm. The peat sample from 270–267.5 cm (Fig. 19:6) yields a lower limit of 9 150 ± 140 ^{14}C years B.P. The gyttja sample at 293–289 cm taken just above the boundary gave 9 710 ± 100 years B.P. as the mean of two fractions without correction for reservoir age and possible contamination *in situ.*

The distribution diagrams in Fig. 19:6 therefore suggest some limits for the Pleistocene/Holocene boundary, which is thus dated to a zone between 9 200 and a value probably below *c.* 9 500 ^{14}C years B.P.

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REFERENCES

Deevey, E.S., Jr, Gross, M.S., Hutchinson, G.E., and Kraybill, H.L., 1954: The natural C^{14} contents of materials from hard-water lakes. – Proc. Nat. Acad. Sci., Washington, 40, 285–288.

Donner, J.J., and Jungner, H., 1973: The effect of re-deposited organic material on radiocarbon measurements of clay samples from Somero, southwestern Finland. – Geol. Fören. Stockh. Förh. 95, 267–268.

Donner, J.J., and Jungner, H., 1974: Errors in the radiocarbon dating of deposits in Finland from the time of deglaciation. – Bull. Geol. Soc. Finland 46, 139–144.

Donner, J., and Jungner, H., 1980: Radiocarbon ages of shells in Holocene marine deposits. – Radiocarbon 22, 556–561.

Eriksson, K.G., and Olsson, I.U., 1967: Några data från en planerad undersökning av en skalbank vid Linddalsskogen, Väjern, Mellersta Bohuslän. – *In* Teknik och Natur, Studier tillägnade Gunnar Beskow den 30 juni 1967. – Akademiförlaget, Göteborg. 149–166.

Fries, M., 1951: Pollenanalytiska vittnesbörd om senkvartär vegetationsutveckling, särskilt skogshistoria, i nordvästra Götaland. – Acta Phytogeographica Suecica 29, 220 pp.

Geyh, M.A., Merkt, J., and Müller, H., 1970: ^{14}C-Datierung limnischer Sedimente und die Eichung der ^{14}C-Zeitskala. – Naturwissenschaften 57, 564–567.

Hörnsten, Å., and Olsson, I.U., 1964: En C^{14} datering av glaciallera från Lugnvik, Ångermanland. – Geol. Fören. Stockh. Förh. 86, 206–210.

Mörner, N.-A., 1976: Radiocarbon dates. – Boreas 5, 240–243.

Olsson, I.U., 1966: Computer calculations of C^{14} determinations. – Uppsala Univ. Inst. Physics Rep. UUIP-477, 1–11.

– 1972: The C^{14} dating of samples for botanical studies of prehistoric agriculture in northern Ångermanland. – *In* Early Norrland 1, 35–41. – Kungl. Vitterhets, Historie och Antikvitets Akademien, Stockholm.

– 1973: A critical analysis of ^{14}C datings of deposits containing little carbon. – *In* Proc. 8th Int. Conf. Radiocarbon Dating, Lower Hutt, Oct. 18–25, 1972. – Royal Society of New Zealand, Wellington, G11–G28 (547–564).

– 1978: A discussion of the C^{14} ages of samples from Medelpad, Sweden. – *In* Early Norrland 11, 93–97. – Kungl. Vitterhets, Historie och Antikvitets Akademien, Stockholm.

– 1979: A warning against radiocarbon dating of samples containing little carbon. – Boreas 8, 203–207.

– 1980: Content of ^{14}C in marine mammals from northern Europe. – Radiocarbon 22, 662–675.

– 1982: Dating non-terrestrial materials (in press).

Olsson, I.U., and Florin, M.-B., 1980: Radiocarbon dating of dy and peat in the Getsjö area, Kolmården, Sweden, to determine the rational limit of *Picea*. – Boreas 9, 289–305.