mud is of limnic origin and that the specific activity of water plants may depend on whether they photosynthesize CO_2 from the air and CO_2 dissolved in the water, or they photosynthesize bicarbonate. In view of these considerations, the mean specific activity for this group of material was tentatively taken to be 1% higher than the corresponding value for wood.

On the basis of these assumptions the mean age determination of the samples from the transition period between Allerød and Younger Dryas, as shown in Fig. 2, is calculated to be 10.870 ± 130 years. With an error in the mean value of this magnitude, however, the uncertainties in the determination of the half-life of C^{14} and of the value for modern wood are no longer negligible. If this is taken into account, the date becomes 10.870 ± 160 years.

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Radiocarbon Dating of the Alleröd Period

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THE AIM of the first radiocarbon assays in Copenhagen[1] is the dating of the late glacial Alleröd period, and, at the same time, a check of the applicability of certain material taken from sediments of various types.

The Alleröd period covers a great, late glacial, climatic fluctuation first demonstrated at Alleröd in North Zealand by Hartz and Milthers in 1901 (*1*). In the clay walls of the brickwork at Alleröd, we find a continuous band of pure organogenic lake mud, containing remains of a temperate flora and dividing the clay into an upper and a lower bed. Both beds are characterized by Arctic plant fossils, e.g., Dryas octopetala. Obviously, the mud layer represents a mild phase, the Alleröd period (Zone II), interposed between two cold periods, the Older Dryas Period (Zone I), and the Younger Dryas Period (Zone III). This classical Alleröd section has since been found in numerous other places in Denmark (e.g., Ruds-Vedby, Fig. 1). The same climatic development can be demonstrated by pollen analysis everywhere in Danish late glacial series, even where the stratigraphy is different.

In later years, the Alleröd oscillation has been alleged in many other countries in northwestern Europe and also in the Alps. In North America, a late glacial bed containing tree trunks that have succumbed to a new advance of the ice (Two Creeks Forest bed [*2*]) has been compared with the Alleröd section. A proof that a local climatic oscillation in late glacial times is part of a universal development, identical with the Alleröd period, can be furnished only by an unambiguous demonstration of the synchronism of these events. For the time being, the only means of absolute dating is the radiocarbon method. It there-

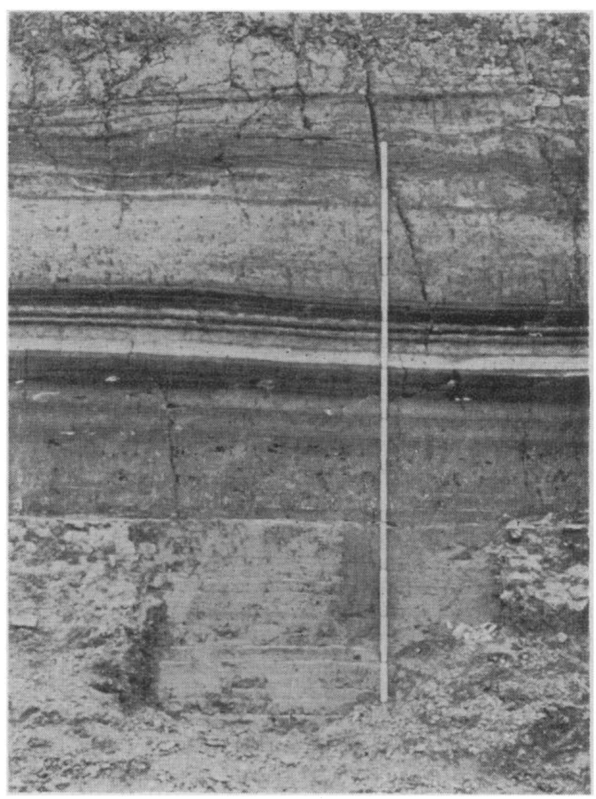

FIG. 1. Part of Alleröd section at Ruds-Vedby. Clay above and beneath: layers of organogenic lake mud (dark) and lake marl (white) in the middle cover the Alleröd period.

[1] Cf. the paper by Anderson, Levi, and Taüber, "Copenhagen Natural Radiocarbon Measurements," also in this issue.

fore is of great interest to carry out an absolute dating of the Alleröd oscillation in the classical Danish region and subsequently compare these dates with datings from other supposed Alleröd beds.

For the purpose of establishing a reference, samples from an exposed Alleröd section at Ruds-Vedby in Zealand were taken. Here, the Alleröd stratigraphy presents itself in the classical form as a layer of organic lake mud interposed between two thick layers of clay (Fig. 1). The section is characterized by a distinct layering, each of the thin layers being synchronous. The composition of the layers varies greatly, and therefore it has been possible to procure material of different types, viz., wood, peat mud, and lake marl.

Figure 2 is a pollen diagram from the location where the C^{14} samples were taken. To make the figure comprehensible for nonspecialists in this field the details have been omitted from the diagram.[2] Only the fluctuating frequency of trees, shrubs, and herbaceous plants is given. It appears from the diagram that while pollen of herbaceous plants (indicating the tundra) dominate in the Older and Younger Dryas clay (Zones I and III), the Alleröd deposits (lake mud and lake marl) are characterized by the preponderance of tree pollen; this is evidently true in the lake marl which, in this case, represents the climatic optimum (Zone IIb). The following decline is indicated by the abrupt fall in the tree-pollen frequency and the corresponding rise in pollen frequency of herbaceous plants.

This horizon—the zone border II–III—is the sharpest horizon in the Danish pollen diagrams and is definitely synchronous. For this reason, we have made a great effort to arrive at an exact date of this horizon. The mean of 5 determinations (K-101A, B, C; K-102; and K-103) is 10,830 ± 200 years; this figure, therefore, represents the age of the upper limit of the Alleröd period.

K-106 (11,880 ± 340) is from the very end of Zone IIa, the early part of Alleröd, immediately before the climatic optimum was reached. If this figure is compared with the dating of the zone border II–III, we notice a difference of about 1000 years. Although the statistical error of the results is considerable, we can conclude on the basis of these radiocarbon datings, that the Alleröd period covers at least one millennium.

All the deposits in the Ruds-Vedby section are rich in lime, and this may cause intrusion of carbon of different age. Besides the free CO_2, dissolved bicarbonate may also be an immediate source of carbon for submerse aquatic plants during photosynthesis. Some of the carbon in the bicarbonate of Danish lakes derives from free CO_2, some, however, from pre-Quaternary chalk. While the former will have the specific activity of the exchange reservoir, the latter will be practically inactive; yet exchange processes will tend to produce a specific activity corresponding to that prevailing in water in equilibrium with the atmosphere. If this exchange is a slow process, submerse plants from lakes rich in lime will show a considerable deficiency in C^{14}. Radiocarbon datings from calcareous lake deposits will then turn out too old.

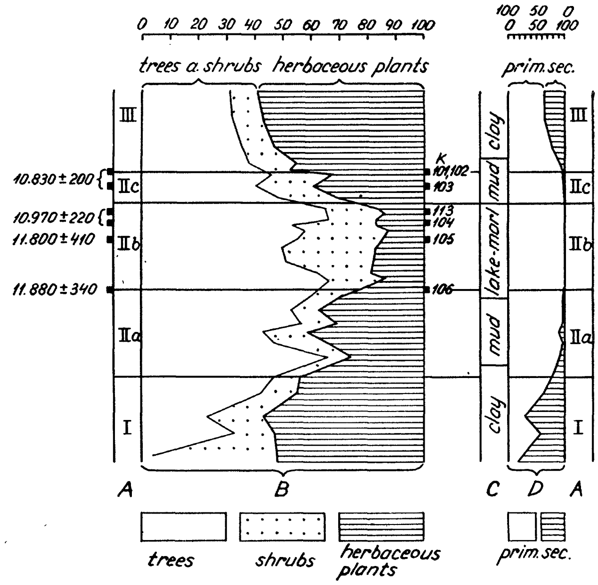

FIG. 2. Pollen diagram from the center part of the Alleröd section at Ruds-Vedby. A. The zoning system according to Knud Jessen (I Older Dryas period. II Alleröd period, III Younger Dryas period). B. Total pollen diagram; all individual pollen curves have been omitted. C. Stratigraphy. D. The frequency of secondary pollen, i.e., pollen deriving mainly from old, pre-Quaternary deposits, and washed in from pollen containing boulder clay. This influx indicates unfavorable climatic conditions, and the Alleröd-oscillation is reflected in the curve of secondary pollen (*10*).

This problem has been studied by comparing the result of radiocarbon measurements on sample K-113 (lake marl) with those of K-101 (wood) and K-110 (noncalcareous lake mud). According to pollen analysis, these three samples are almost contemporaneous. Samples K-101 and K-113 are from Ruds-Vedby (Fig. 2); K-110 is from an Alleröd section located in a very poor outwash-plain in Jutland, near the former Bölling lake. K-110 derives from a thin peaty mud layer; pollen analysis classifies it as being from the boundary between Zones II and III. The results obtained are as follows:

K-113	Lake marl	10,930 ± 300
K-101	Wood	10,890 ± 240
K-110	Noncalcareous lake mud	10,770 ± 300

The fact that these figures are identical within statistical error shows that radiocarbon measurements of highly calcareous lake sediments can give reliable dates.

The sample K-114 is from the same material as K-113; but while K-113 represents a measurement carried out on organic matter, K-114 is made on lime isolated from the same material. The figure for K-114 is somewhat higher (12,280 ± 480), which seems to indicate that equilibrium with the exchange reservoir was not yet reached when the lime was precipitated.

[2] The pollen analyses have been carried out by H. Krog; the detailed pollen diagram will be published elsewhere.

On the other hand, the difference seems sufficiently small to confirm that in this sample, intrusion of carbonate-carbon into organic matter is of little significance for the dating results (cf. Anderson, Levi, and Tauber, this issue).

K-111 (10,300 ± 350) from the Bölling section dates the boundary between the late glacial and postglacial period, the zone border III–IV, which is characterized by a rapid spreading of the forest as the result of considerable climatic improvement. It is generally assumed that this event is synchronous with the final retreat of the ice from the central Swedish moraines. From this period, we have the oldest fairly reliable date which is based on the Swedish varved clay chronology, viz., 10,060 prior to our time (*3*). It is remarkable how well the radiocarbon dating of the zone border III–IV (K-111: 10,300 ± 350) agrees with this date, especially in view of the fact that the varved clay chronology has a considerable margin of error. The weak point in the dating is that it depends on the linkage of a varve chronology covering the early end of the scale (*3*) with another one covering the later end up to our time (Liden). If there is a gap between these scales, as suggested by Sauramo (*4*), the date given above (about 10,060 years) is too low. The agreement between the results obtained earlier and our radiocarbon date, however, seems to indicate that the gap is smaller than supposed by Sauramo.

Finally, the sample K-107[3] is from a profile at Wallensen in Hannover (Germany), which has been attributed to the Alleröd period by Firbas (*5*) owing to a very similar stratigraphy and pollen diagram. A sample from the upper part of the mud layer, corresponding to our Zone IIb, has been dated by Arnold and Libby (*6*); the figure (11,044 ± 500) is in perfect agreement with the new Danish dating (11,160 ± 320). A comparison with the radiocarbon dates from Ruds-Vedby proves that Firbas correctly referred the Wallensen mud layer to the Alleröd period (*7*).

[3] This sample was submitted by Firbas and the material is identical with that dated by Libby.

From the British Isles radiocarbon datings from four supposed Alleröd localities are available.

No. 355	Lake mud at Knocknacran, County Monaghan, Ireland (F. Mitchell)	11,310 ± 720
No. 444	Lake mud from Neasham near Darlington, Northumberland, England (H. Godwin and K. Blackburn)	10,851 ± 630
No. 341	Peat from Hawks Tor, Cornwall (H. Godwin)	9,861 ± 500
No. 349	Calcareous silty necron mud, Hockham Mere, Norfolk (H. Godwin)	6,555 ± 280

Godwin (*8*) has discussed these datings thoroughly. The sample 349 should be disregarded because the material was collected using a rather unsafe method (*8*). The date of No. 341 is somewhat too low for Alleröd, but the pollen analysis from the peat (cf. [*9*], Tables 6–7), in the present author's opinion, does not exclude the possibility that the material was deposited during the Younger Dryas period (Zone III); this is fairly consistent with the result of the C^{14} dating.

The geological classification of the Irish section (No. 355) and of the section in Northumberland (No. 444), however, is very convincing as belonging to the Alleröd period. These classifications are indeed confirmed by the radiocarbon dating.

The synchronization of the Two Creeks forest bed (cf. above) in the U.S. with the Alleröd period already seemed highly probable on the basis of the radiocarbon datings published by Arnold and Libby (*6*); the new dates from the Danish Alleröd strata finally settle the question. The mean of 5 datings on material from Two Creeks is 11,400 ± 350 (*6*), while the Alleröd period according to the Danish dates, ranges from about 12,000 to 10,800 years prior to our time. The great importance of this transatlantic correlation has already been discussed by Flint and Deevey (*11*). The Alleröd oscillation now appears to be universal, at least in the Northern Hemisphere.

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