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EXTENSION OF THE HOLOCENE DENDROCHRONOLOGY BY THE PREBOREAL PINE SERIES, 8800 TO 10,100 BP

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ABSTRACT. Holocene tree-ring chronologies have been established for south-central Europe covering the past 11,000 years. The Hohenheim absolute oak chronology extends to 4089 BC. The ^{14}C-calibrated mid-Holocene floating oak master covers a 3181-year period from ca 4045 to 7225 BC. The earliest well-replicated floating oak master (estimated calendar age 7215 to 7825 BC) extends the European oak dendrochronology back to Boreal times.

Further extension of the Holocene dendrochronology has been achieved by subfossil oak and pine trees from the Rhine, Main, and Danube Rivers. A 774-year floating series of Preboreal pine has been established. ^{14}C ages range (from younger to older end) from 9200 to 9800 BP. Within this series a major atmospheric ^{14}C variation is indicated, resulting in nearly constant ^{14}C ages (9600 BP) over a period of 370 tree-rings.

The European oak and pine tree-ring chronologies cover without major gaps the entire Holocene epoch. Based on the length of the dendro-records, an approximate solar year age of 11,280 years is calculated for the Holocene/Pleistocene boundary.

The Preboreal pine forests along the rivers were replaced by mixed oak forests between 9200 and 8800 BP. By linking the earliest oak masters and the Preboreal pine series, the European dendrochronology can be extended up to the end of Late Glacial times.

THE HOHENHEIM OAK DENDROCHRONOLOGY—PRESENT TO 4089 BC

In 1982 we noticed an offset of 70 years between the tree-ring time scale and the matching of its ^{14}C variations to those of the Bristlecone Pine (Becker, 1983). In cooperation with the Belfast and Cologne Tree-Ring Laboratories, oak chronologies of Northern Ireland, England, and northern and southern Germany have been cross-matched over the first and second millenium BC. After a correction of the Hohenheim series at 500 BC by 71 years, the Hohenheim and the Belfast oak masters evidently cross-date continuously over their critical bridgings of the first millennium BC (Pilcher *et al,* 1984).

The Hohenheim oak master has been used for ^{14}C studies carried out by various laboratories. La Jolla measurements of the period AD 250 to 4000 BC were recently published (Linick, Suess & Becker, 1985). High-precision ^{14}C measurements for the period 1 to 2000 BC have been established by Minze Stuiver of Seattle (Stuiver *et al,* 1986). John Vogel of Pretoria has carried out ^{14}C analyses of Hohenheim oak samples of the third millennium BC (Vogel *et al,* 1986). For the fourth millennium BC, the Groningen Laboratory has measured the ^{14}C variation of the Hohenheim Neolithic oak master (de Jong, 1981; de Jong, Becker & Mook, 1986).

In addition to its use for ^{14}C calibration, the Hohenheim oak master provides a solid base for dendro-dates of south-central European prehistory. In cooperation with the Tree-Ring Laboratories at Hemmenhofen (A Billamboz), Neuchatel (H Egger & P Gassmann), Moudon (A & Chr Orcel) and Zurich (U Ruoff & coworkers) more than 130 prehistoric oak dwelling settlements have been dendro-dated (Becker *et al,* 1985; Billamboz & Becker, 1985). The dendro-dated sites are located on lake shores and mires of eastern France, western and northern Swiss lakes, Lake Bodensee, and southwest Germany.

According to the dendro-dates, these dwelling settlements were constructed during Neolithic and Bronze Age times, beginning in the 38th and ending in the 9th century BC (Table 1). They confirm earlier ^{14}C calibrations of Neolithic dwelling settlements (Ferguson, Huber & Suess, 1966), which have been questioned by archaeologists for some time.

THE MID-HOLOCENE FLOATING HOHENHEIM OAK MASTER : 4045–7225 BC

Since 1982 the earlier floating mid-Holocene oak series, Donau 8, Main 6/13, and Main 4/11 (Becker, 1983) have been linked together to yield a continuous 3181-year floating series. According to the ^{14}C calibration of this sequence by the La Jolla Laboratory, the series covers the period 4035 to 7215 BC (Linick, Suess & Becker, 1985). Recent measurements of Seattle and Heidelberg confirm this calibration (Stuiver *et al,* 1986; Kromer *et al,* 1986), which results in an extension beyond the Bristlecone Pine sequence of an additional 500 years.

The Hohenheim mid-Holocene oak master consists of 266 individual oaks from the Main River, and is replicated by 72 additional oaks from the Danube and Rhine Rivers over 2307 years of the Main chronology.

EARLY HOLOCENE OAK CHRONOLOGIES : 7800 TO 9000 BC

An Early Holocene dendrochronologic extension was achieved by collecting subfossil oaks from the Early Boreal period. The oldest well-replicated floating oak master (Main 9) dates before the calibrated mid-Holocene floating master mentioned above. A comparison of the ^{14}C ages of the end of the Main 9 series with the beginning of the floating calibrated master yields a calendar age of the series of 7215 to 7825 BC (Kromer *et al,* 1986).

The Main 9 series marks the end of well-replicated oak chronologies, but some subfossil oaks are still older then the Main 9 series. According to conventional ^{14}ages, these earliest Holocene oaks started to grow in the Rhine valley at 9200 BP, in the Danube at 8890 BP, Main and Mosel valleys at 8860 BP, and the Mosel valley at 8800 BP. The Early Holocene Danube, Mosel, and Main/Regnitz series are replicated by 3 to 8 cross-dated individuals (Fig 1).

PREBOREAL PINE CHRONOLOGIES : 8900 TO 10,150 BP

We have sampled 128 pine trees (*Pinus sylvestris*) deposited in fluvial gravels along the Rhine and Danube Rivers. ^{14}C dates show that the earliest pine stands must have already developed during the Bölling and Alleröd Interstadials. Most of the sampled trees date from the Preboreal period. Three floating Preboreal masters were established. The largest series (B–C) consists of 55 samples resulting in a 774-year tree-ring record.

The ^{14}C ages of the series A and B are shown in Figure 2. There is evidence for a substantial ^{14}C variation between 9800 and 9500 BP indicated by a sharp transition between 9750 and 9900 BP measured in series A and a flat region between 9650 and 9550 BP in series B–C corresponding to 350 solar years (Table 2).

A similar decrease in ^{14}C age relative to solar years was observed in peat bog sediments of the Wachseldorn site in Switzerland (Oeschger *et al,* 1980). However, comparing these data with our measurements on pine tree rings, the Wachseldorn sequence appears to be shifted by 250 years to older ages.

The last Preboreal floating pine series (D, Fig 1) covers the period of ca 8900 to 9100 BP. From this sequence the linkage between the Early Holocene pine and oak chronologies can be expected.

ABSOLUTE AGE ESTIMATE OF THE HOLOCENE/PLEISTOCENE BOUNDARY

The successful construction of a 774-year pine master and the establishment of replicated pine and oak series in the gap between this master and the Main 9 oak master encourages further extensions of the dendrochronology and its ^{14}C calibration back to the Pleistocene/Holocene boundary. The earliest Holocene pine series (A) consists of a floating 194-year sequence, which covers by 5 cross-matched trees the period of ca 9800 to 10,000 BP. Also, three individual pines reach back to 10,150 BP.

If we assign these earliest Holocene pine trees to the transition from Younger Dryas to Preboreal we can derive a lower limit for the calendar age of the Holocene/Pleistocene boundary:

The three large Holocene oak masters together with the Preboreal pine master B–C span a period of 10,600 dendro-years. We estimate the time span between the beginning of the oak master Main 9 and the end of the Preboreal pine master B–C to be equal to the difference in ^{14}C years (400 yr), and estimate an additional 300-year interval between the Preboreal pine master and the period covered by the oldest Preboreal pine samples mentioned above. With these estimates, the Holocene period spans 11,280 dendro-years. It should be noted that the uncertainty in this estimate is biased to an even larger age in dendro-years as lower real ages of the floating chronologies (*ie,* smaller gaps) would require larger overlaps of the already existing dendro-series, which should be detectable dendrochronologically.

Using this calculation and the ^{14}C age of the oldest Preboreal pine sample (10,150 BP), we calculate $\Delta\,^{14}C$ at the Pleistocene/Holocene boundary to be $+110‰$. Judging from the already existing tree-ring series covering the two remaining gaps in the Hohenheim dendrochronology, this value cannot be lower than $90‰$. Thus, the atmospheric ^{14}C level appears to have been already at its high level at the beginning of the Holocene (Table 3).

PALEOCLIMATIC EVIDENCE AS SEEN IN THE PREBOREAL PINE SERIES

The radiometric data provide good evidence that the Preboreal pine forests along the valleys of the Rhine and Danube Rivers must have been replaced by immigrating oaks between 9200 and 8900 BP. The transition from Preboreal pine-birch forests to hazel-oak and mixed oak forests is well known from various central European lowland pollen profiles. However, considering the dates of the subfossil tree remnants given above, this transition must have occurred very rapidly, eg, probably during a single generation of trees. Comparing the latest pine dates and the earliest oak dates from various valley regions in south-central Europe, it seems that during the spreading of a deciduous forest community by the re-immigrating oaks, a dense forest canopy must have developed quickly. Within these mixed pine-oak alluvial forests the pine, a light-demanding tree species, very probably could no longer regenerate and therefore became displaced within a very short time period.

Holocene valley oak tree-ring patterns of the past 9000 years show substantial variations of tree growth, which can be related to natural changes and man-made disturbances of the paleohydrology of the rivers (Becker, 1982). However, drastic climatic variations are not obvious from this study of Holocene oak remnants. The subfossil Preboreal pines seem to provide much better information for past environmental conditions that controlled tree growth. Many of the pine cross-sections have remarkable growth depressions often with partly or completely missing rings. Some of the missing rings can only be detected after cross-matching a large number of individuals. For example, within one of the Preboreal pines, 12 partly missing rings were detected over an extreme 40-year growth depression. After cross-matching the curve with the Preboreal master, an additional 3 totally missing rings were found.

The subfossil pine trunks often have injuries, which later are overgrown with the uninjured parts of the stem. Other damages are deep vertical splits formed repeatedly, because the tree could close them only by developing bark, which sometimes reaches close to the center of the stem. Forest fires can be excluded as a causal factor, because charcoal should then have been preserved as well as the, indeed well-preserved, timber and bark.

Two explanations are possible for the damage to the Preboreal pines: 1) considering the fluvial dynamics of their environment, floods with drifting ice blocks could have damaged the pines after the melting of frozen rivers. Such features were recently described from living pines on the Oulanka River in northeast Finland (Koutaniemi, 1984); 2) the large vertical splits probably result from repeated splitting of frozen stems during severe winter frost periods. Forest damage of that kind can be observed within contemporary lowlands of the Rhine-Main-Danube region only on very sensitive tree species such as ash. However, they do not occur in this region on pines, which are able to tolerate extreme winters.

If the damage to the subfossil trees would indeed have been caused by flooding with floating ice blocks and by frost splitting, then it can be concluded that remarkably low winter temperatures existed in south German lowlands during Preboreal times.

SUBFOSSIL PINES FROM THE ALLERÖD AND BÖLLING INTERSTADIALS

A first floating pine master has been linked together for the Alleröd period (ALL 1, Fig 3). This series consists of 3 individual trees, which span a total number of 335 years. ^{14}C dates indicate a growth period from ca 11,800 to 11,465 BP. Two additional samples date from ca 11,300 to 11,000 BP. These samples provide a chance for the construction of a larger Alleröd sequence. A single pine was collected from the Isar River, dating from the Bölling Interstadial at ca 12,180 to 12,000 BP.

It should be stressed that among the hitherto sampled fluvial pines, not a single tree remnant was found from the Older and Younger Dryas Stadials. This lack of evidence seems to indicate that the Bölling and Alleröd pine stands became extinct during the climatic deteriorations of the following Stadials.

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REFERENCES

Becker, B, 1982, Dendrochronologie und Paläoökologie subfossiler Baumstämme aus Flussablagerungen: Mitt Komm Quartärforschung Österr Akad Wiss, v 5, 120 p.

——— 1983, The long-term radiocarbon trend of the absolute German oak tree-ring chronology, 2800 to 800 BC, *in* Stuiver, M and Kra, R S, eds, Internatl ^{14}C conf, 11th, Proc: Radiocarbon, v 25, no. 2, p 197–203.

Becker, B, Billamboz, A, Egger, H, Gassmann, P, Orcel, A, Orcel, C and Ruoff, U, 1985, Dendrochronologie in der Ur- und Frühgeschichte: Antiqua, v 11, p 1–68.

Billamboz, A and Becker, B, 1985, Dendrochronologische Eckdaten der neolithischen Pfahlbausiedlungen Südwestdeutschlands: Ber Ufer- u Moorsiedl Südwestdeutschl, v 2, p 10–15.

Ferguson, C W, Huber, B and Suess, H E, 1966, Determination of the age of Swiss lake dwellings as an example of dendrochronologically-calibrated radiocarbon dating: Zeitschr Naturforschung, v 21, no. 34, p 1173–1177.

Jong, A F M, de, (MS) 1981, Natural ^{14}C variations: PhD dissert, Univ Groningen.

——— 1986, High-precision calibration of the radiocarbon time scale: 3930–3230 BC, *in* Stuiver, M and Kra, R S, eds, Internatl ^{14}C conf, 12th, Proc: Radiocarbon, this issue.

Kaiser, K F, 1975, Ein eiszeitlicher Wald in Dättnau: Mitt Naturwiss Ges Winterthur, no. 34, p 25–42.

Koutaniemi, L, 1984, The role of ground frost, snow cover, ice break-up and flooding in the fluvial processes of the Oulanka River, NE Finland: Fennia, v 162, no. 2, p 127–161.

Kromer, B, Rhein, M, Bruns, M, Schoch-Fischer, H, Münnich, K O, Stuiver, M and Becker, B, 1986, ^{14}C calibration data for the 6th to the 8th millennium BC, *in* Stuiver, M and Kra, R S, eds, Internatl ^{14}C conf, 12th, Proc: Radiocarbon, this issue.

Linick, T W, Suess, H E and Becker, B, 1985, La Jolla measurements of radiocarbon on South German oak tree-ring chronologies: Radiocarbon, v 27, no. 1, p 20–30.

Oeschger, H, Welten, M, Eicher, U, Möll, M, Riesen, T, Siegenthaler, U and Wegmüller, S, 1980, ^{14}C and other parameters during the Younger Dryas cold phase, *in* Stuiver, M and Kra, R S, eds, Internatl ^{14}C conf, 10th, Proc: Radiocarbon, v 22, no. 2, p 299–310.

Pilcher, J R, Baillie, M G L, Schmidt, B and Becker, B, 1984, A 7272-year tree-ring chronology for western Europe: Nature, v 312, no. 5990, p 150–152.

Stuiver, M, Kromer, B, Becker, B and Ferguson, C W, 1986, Radiocarbon age calibration back to 13,300 yr BP and the ^{14}C age-matching of the German Oak and US Bristlecone Pine chronologies, *in* Stuiver, M and Kra, R S, eds, Internatl ^{14}C conf, 12th, Proc: Radiocarbon, this issue.

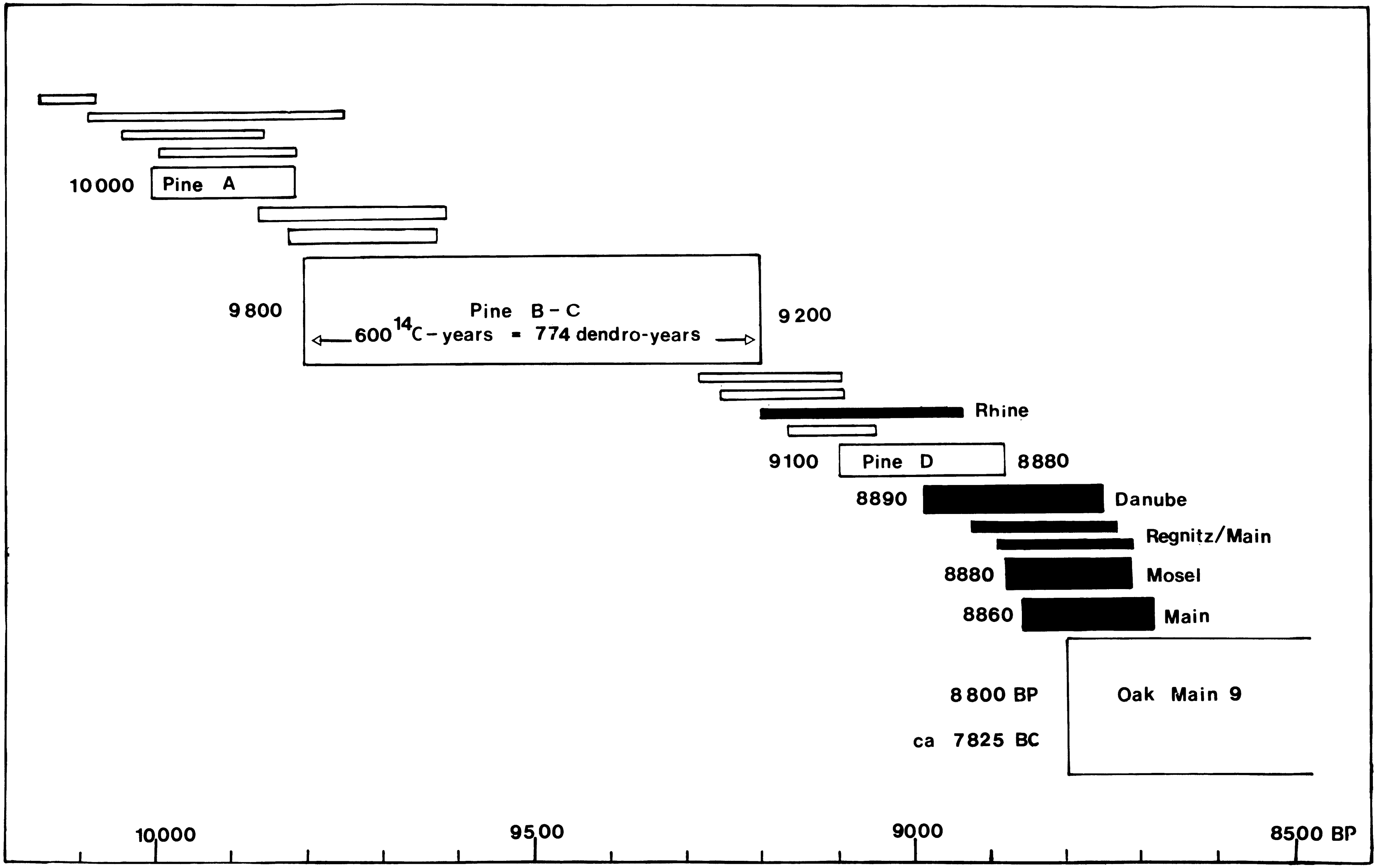

Fig 1. Present stage of Early Holocene European oak and pine tree-ring chronologies. Small blocks represent individual trees; medium-sized blocks, series replicated by 3 to 8 individuals; large blocks, well-replicated masters. White blocks = Scotch pine, black blocks = oak.

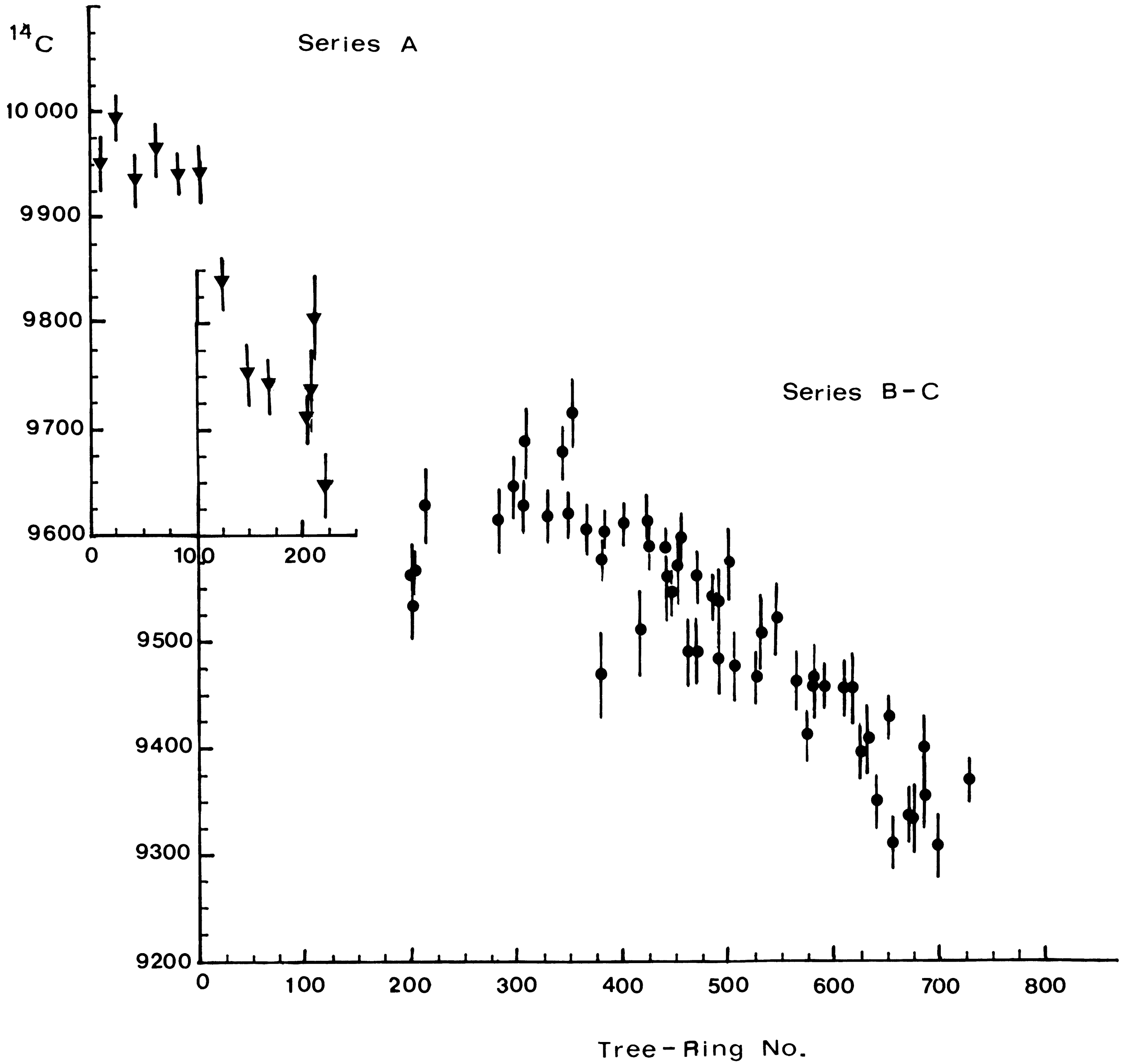

Fig 2. ^{14}C ages *vs* ring numbers of the Preboreal pine series A and B–C. Both series are floating, therefore, the transition from A to B–C is not yet fixed dendrochronologically.

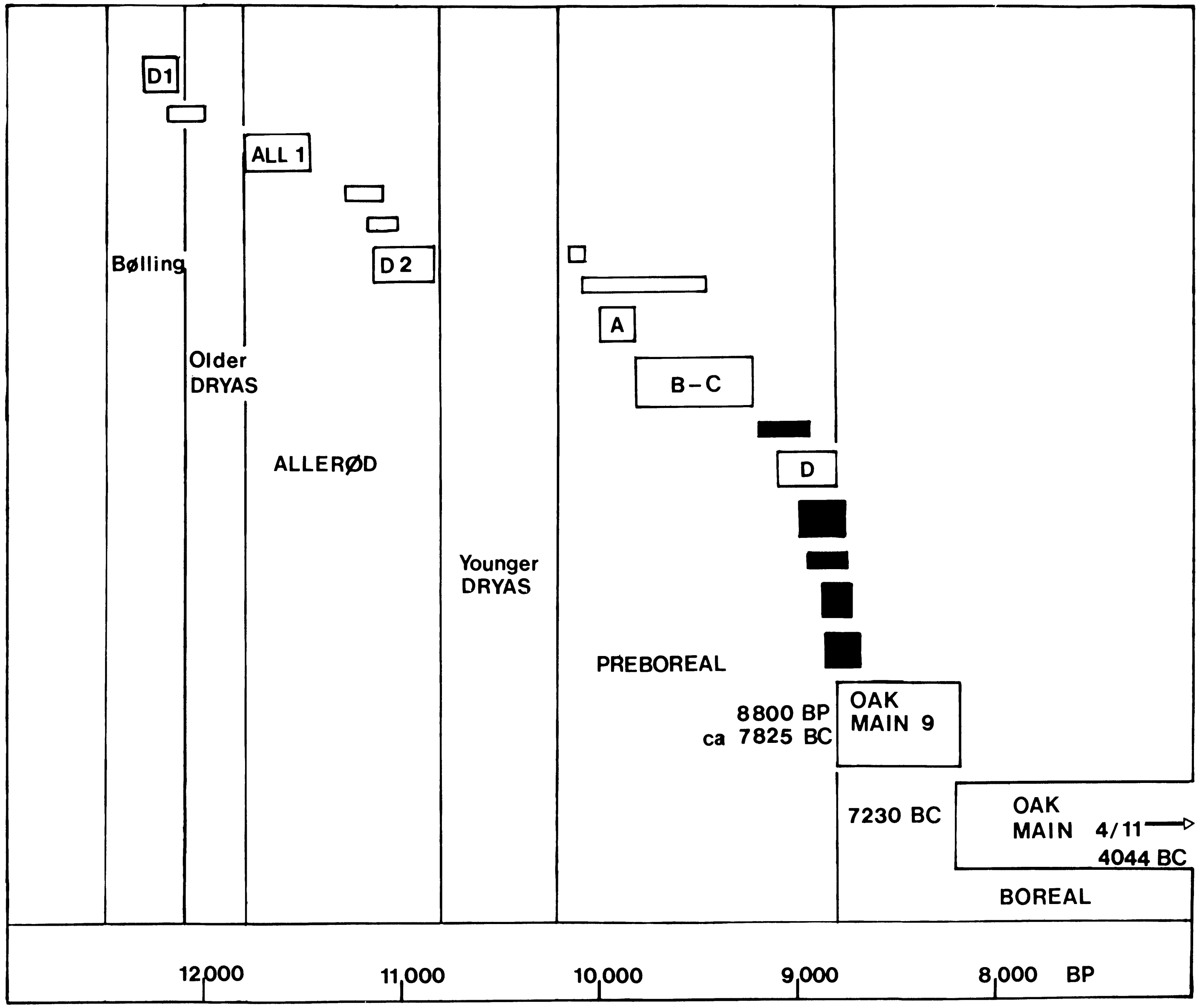

Fig 3. Late Glacial pine and Early Holocene pine-oak dendrochronologies. Black blocks = oak; series D1 and D2 are from Dättnau/Switzerland (Kaiser, 1975).

TABLE 1

Dendro-dates of Neolithic and Bronze Age dwelling sites of eastern France, Switzerland, and southwest Germany, derived by the Tree-Ring Laboratories of Hemmenhofen, Neuchatel, Moudon, and Zurich by cross-dating with the Hohenheim oak master

Region	Dendro-dated cultures		
SW Germany	Late Neolithic 3850–3650 BC (7)	End of Late Neolithic 3590–3510 (2)	End of Late Neolithic 3330–3260 BC (3)
W Switzerland E France	Classic Cortaillod 3860–3680 BC (8)	Late Cortaillod 3630–3550 BC (5)	Horgen 3290–2980 BC (11)
N Switzerland	Pfyn and 3820 to	Cortaillod 3530 BC (16)	Horgen 3240–2870 BC (6)
SW Germany	End. Neolithic 3080–2670 BC (4)		Early Bronze Age 1760–1500 BC (2)
W Switzerland & E France	Lüscherz	Saone-Rhone civilization	Early Bronze Age
N Switzerland	2800–2700 BC (12) Corded Ware ceramics 2760–2690 BC (7)	2630–2420 BC (7) Late Corded Ware ceramics 2600–2460 BC (3)	1650–1610 BC (1) Middle Bronze Age 1660–1500 BC (3)
SW Germany	Late Bronze Age 1060–850 BC (2)		
W Switzerland & E France	Final Bronze Age		
N Switzerland	1080–850 BC (28) Late Bronze Age 1100–910 BC (11)		

The dendro-dates (approximated to decennia) specify series of cutting dates, beginning with the earliest and ending with the last dwelling site of a culture within the region. Dendro-dates and their associations with prehistoric cultures, as well as archaeologic terms, according to the contributions of A Billamboz, H Egger and P Gassmann, A and C Orcel, and U Ruoff *in* Becker *et al* (1985). The numbers in parentheses are the numbers of the dated sites. In most cases each site contains several dendro-dated structures.

TABLE 2

Radiocarbon measurements of tree rings of the 774-year Preboreal Hohenheim pine chronology. The data are listed from the oldest to the youngest ring of the floating series.

HD-no.	Tree-ring no.	^{14}C age (BP)	HD-no.	Tree-ring no.	^{14}C age (BP)
−9423	*102–107	9684 ± 40	−7536	*461–466	9486 ± 40
−9424	*106–111	9850 ± 40	−7601	*467–476	9488 ± 40
−9427	*107–117	9781 ± 40	−8889	471–474	9559 ± 25
−8657	*117–127	9647 ± 31	−8690	486–489	9540 ± 20
−8752	*197–207	9560 ± 31	−7573	*489–494	9535 ± 40
−8656	200–206	9532 ± 30	−7917	*490–496	9481 ± 40
−9428	*201–209	9564 ± 22	−8910	501–504	9572 ± 34
−8753	*211–222	9628 ± 35	−8911	506–509	9474 ± 34
−9449	*284–286	9612 ± 31	−7915	*527–530	9466 ± 40
−9466	*293–306	9644 ± 29	−8904	531–534	9506 ± 34
−9280	*308–312	9687 ± 32	−8905	546–549	9520 ± 34
−9065	304–312	9627 ± 24	−8977	561–569	9462 ± 25
−9075	329–332	9616 ± 26	−9026	574–577	9410 ± 20
−9076	344–347	9676 ± 26	−8957	581–584	9463 ± 34
−9087	349–352	9618 ± 22	−8978	581–584	9458 ± 24
−8806	351–360	9712 ± 31	−9007	589–592	9456 ± 20
−8826	366–369	9603 ± 23	−9064	609–612	9454 ± 27
−7623	*377–385	9468 ± 40	−8970	616–619	9455 ± 34
−8835	381–384	9576 ± 20	−9154	624–627	9394 ± 26
−8836	396–399	9601 ± 20	−8971	631–634	9405 ± 34
−8867	401–404	9609 ± 20	−9160	639–642	9348 ± 25
−7572	*413–423	9507 ± 40	−8989	651–654	9428 ± 20
−8795	*421–429	9611 ± 25	−9161	654–657	9309 ± 25
−8868	426–429	9587 ± 20	−9191	669–672	9336 ± 26
−8876	*441–443	9585 ± 40	−8792	*671–679	9331 ± 40
−7566	*441–446	9559 ± 43	−9192	684–687	9354 ± 32
−7608	*446–450	9545 ± 23	−9154	681–689	9398 ± 32
−8758	*449–459	9568 ± 35	−9199	694–702	9307 ± 30
−8877	456–459	9595 ± 20	−7705	*727–730	9368 ± 40
−8658	*461–467	9488 ± 40			

* Indicates ^{14}C dates of tree samples, which were later cross-matched with the master. All other samples were prepared from tree rings of the master for calibration.

TABLE 3

Calculation of the solar-year age of the transition from Younger Dryas to Preboreal times based on Holocene tree-ring records

Dendrochronology	Absolute age of the sequence		Tree rings
Absolute oak master	AD 1985–4089 BC	Dendro-dated	6074
Mid-Holocene oak	4045 BC–7230 BC	Calibrated	3181
Boreal oak Main 9	7215 BC–7825 BC	Calibrated	609
	zeropoint 8800 BP	Conventional BP	
Earliest oak series	8700 BP–9200 BP	Conventional BP	400
Preboreal pine B–C	9200 BP–9800 BP	Conventional BP	774
Oldest pine series	9800 BP–10,150 BP	Conventional BP	300
Tree-ring record of replicated masters			*10,580
Tree-ring record of Early Holocene oaks			400
Tree-ring record of earliest pine trees			300
Total sum of Holocene tree-ring records, dendro-years			11,280
^{14}C age of the earliest Holocene pine, conventional BP			10,150

* Existing overlaps between the series are substracted.