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HOLOCENE DENDROCHRONOLOGICAL STANDARDS FOR SUBFOSSIL OAKS FROM THE AREA OF SOUTHERN POLAND

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Abstract

Subfossil trunks of oak (*Quercus robur* L. and *Q. petraea* Lieb.) are fundamental for construction of long dendrochronological standards for southern Poland. In the last three years over 400 new oak trunks from alluvial deposits from the basins of the rivers Vistula and Odra were analysed. Most trunks came from the last 2500 years and the produced local chronologies permitted for improvement of the standard chronology POLAND2, covering the period 474 BC–1555 AD.

Subfossil oak trunks from several sites in the river Vistula basin (Grabie, Wolica, Podolsze and others) and from alluvia of the river Odra in Wrocław enabled construction of a new long chronology C_3000E, spanning the years 1795-612 BC. This chronology was absolutely dated through teleconnection with standards for southern Germany. A row of floating chronologies, dated with the radiocarbon method, was established for the older periods of Holocene. They cover the following intervals: *ca.* 670–400 BC, *ca.* 2200–1900 BC, *ca.* 3400–3100 BC, *ca.* 3800–3600 BC and *ca.* 6650–6150 BC. Subfossil oak chronologies constructed by the author, together with standards based on living trees, monuments of wooden architecture, and archaeological timbers from Wielkopolska (449–1994 AD), Lower Silesia (780–1994 AD) and Małopolska (910–1997 AD) practically allow for absolute dating of oak timbers from the area of southern Poland coming from the last 4000 years.

Key words: dendrochronology, subfossil oak trunks, Holocene, southern Poland

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INTRODUCTION

Holocene alluvial sediments in Europe often contain subfossil trunks of oak (*Quercus robur* L. and *Q. petraea* Lieb.). In Poland such trees have been known for a long time as "black oaks", because of their black coloration resulting from a reaction between tannine from wood and iron compounds present in ground waters (Krzysik 1978, Kalicki, Krapiec 1995a, and references therein). Aesthetical and practical value of black oaks was known all over Europe, partly due to famous Gdańsk wardrobes produced from black oak timbers (Walczak 1974).

In central Europe first oaks appeared within river floodplains already at the beginning of Holocene (Ralska-Jasiewiczowa 1983, Goslar, Pazdur 1985, Becker 1993). Migration of river beds provoked felling of trees growing on river banks and accumulation of them in sediments. Very often rivers eroded their older alluvia which led to redeposition of trees and, depending on mechanical properties of water-saturated timbers, shaping their surfaces or partial disintegration of trunks (Kalicki, Krąpiec 1995a).

The biggest "black oaks" from the area of Poland lived over 450 years, reaching two metres in diameter and up to 25 metres in length of trunk.

Since 1960s subfossil oaks have been being used in tree-ring studies in Germany, Ireland and England and quickly have become basic material for construction of super-long chronologies (Pilcher *et al.* 1977, 1984, Leuschner 1992). This privileged position of oak is an effect of not only common occurrence of this species in Europe but also of good preservation state of timbers and considerable life-length of trees growing within river floodplains.

In Poland until mid 1980s subfossil oaks had been dated only with the radiocarbon method. First successful tree-ring dating of subfossil trunks from the area of Poland (from Roszków in the valley of the Odra river) against the standard for southern Germany was made by Goslar (1987). In the second half of the 1980s systematic dendrochronological studies started at the Tree-Ring Laboratory of University of Mining and Metallurgy in Cracow. The research was directed at construction of oak standard spanning the longest possible period of time. By mid 1990s, studies on 620 trunks of subfossil oaks from southern Poland resulted in construction of a standard chronology covering over 2000 years, from 474 BC to 1555 AD (Krąpiec 1996a, 1996b). This standard was absolutely dated by teleconnection with chronologies for southern Germany (Becker 1993, Spurk *et al.* 1998, Leuschner, Delorme 1988) and by correlation with three regional chro-

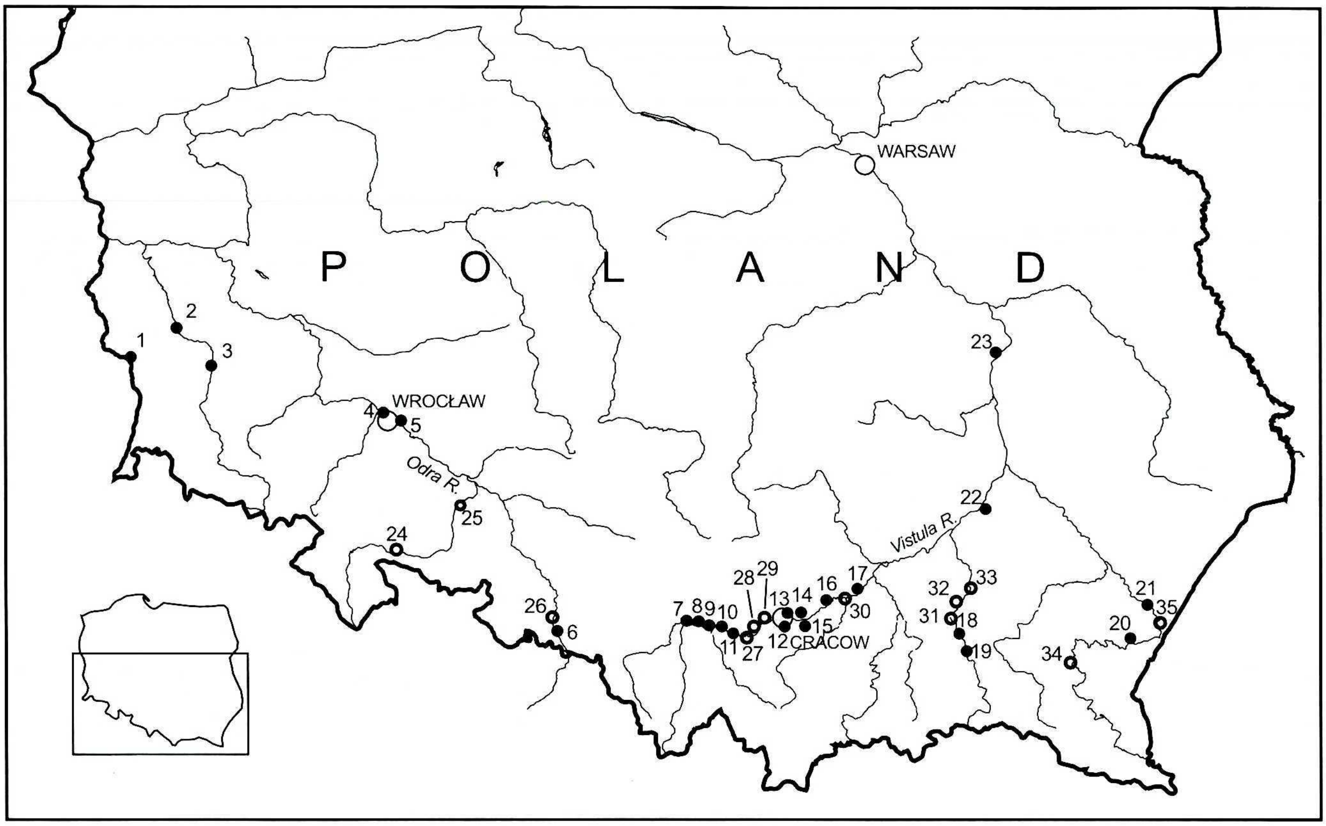

Fig. 1. Location of sites where subfossil oak trunks were sampled for dendrochronological studies in the years 1998–2000 (black circles) and earlier (open circles): 1 – Przewóz, 2 – Gryżyce, 3 – Trzebień–Olszna, 4 – Lenartowice, 5 – Wrocław, 6 – Roszków, 7 – Oświęcim-Dwory, 8 – Przeciszów, 9 – Podolsze, 10 – Smolice-Zakole A, 11 – Smolice-Zakole B, 12 – Grabie, 13 – Cracow–Kujawy, 14 – Branice, 15 – Wolica, 16 – Nowe Brzesko, 17 – Witów, 18 – Klecie, 19 – Wróblowa, 20 – Ostrów, 21 – Radymno, 22 – Machów, 23 – Nasiłów, 24 – Paczków, 25 – Lewin Brzeski, 26 – Krzyżanowice, 27 – Rusocice, 28 – Ściejowice, 29 – Water threshold "Kościuszko", 30 – Niedary, 31 – Strzegocice, 32 – Grabiny, 33 – Kędzierz, 34 – Krzemianna, 35 – Grabowiec.

nologies produced from living trees, architectural and archaeological timbers from the areas of Wielkopolska (449–1994 AD), Lower Silesia (780–1994 AD) and Małopolska (910–1997 AD) (Krąpiec 1998).

Trees from Subboreal and older stages of Holocene, significantly less frequent in alluvial sediments of hitherto researched sites, were used for construction of floating chronologies, dated with the radiocarbon method (Krąpiec 1992).

The results presented in this study are the next step of realisation of the main goal – construction of a long oak standard for southern Poland.

MATERIALS AND METHODS

In Poland, like in other central European countries, subfossil oak trunks are being lifted at exploitation of alluvial gravel as well as at work related to river regulation or construction of sewage treatment plants. Tree trunks, often hindering normal exploitation or construction work, are usually considered as waste materials and, therefore, used practically only for burning. Relatively large amounts of trunks were lifted at gravel exploitation in gravel pits where traditional, mechanical excavators were in use.

Hindering optimal exploitation of the deposit, the trunks were dredged and piled on heaps. This situation, however, has significantly changed in the last years because in most privatised mines economic conditions led to changes in the exploitation system. The new, refulering method enabled submerged exploitation of gravel in the vicinity of subfossil trunks without losses. In these mines dredging and lifting trees to the surface became economically unnecessary, which increased difficulties in collecting material for studies.

In the last three years (1998–2000) 411 oak trunks were sampled in 23 sites, most of them located in southern Poland (Fig. 1). Most samples (339) were taken from sites within the Vistula river basin. 72 samples were taken from the Odra river basin. Samples for the research were being collected in form of slices, 5–10 cm in thickness, cut out with high power petroleum engine saw (Solo 690). After preparation of samples in order to disclose visible anatomic structure of wood and enable identification of annual growth rings, 2–4 measurement tracks along trunk radii, from the core to the outer rings, were delineated. Series of measurements were made with 0.01 mm accuracy at a self-designed apparatus with computer registration of the results (Krąpiec 1995). The measured sequences were then processed with a set of computer programs Tree-Rings (Krawczyk, Krapiec 1995). Individual ring patterns from the same locality were averaged and mutually compared. When contemporary dendrograms were identified, local chronologies were produced and subsequently compared with earlier elaborated standards. In un-

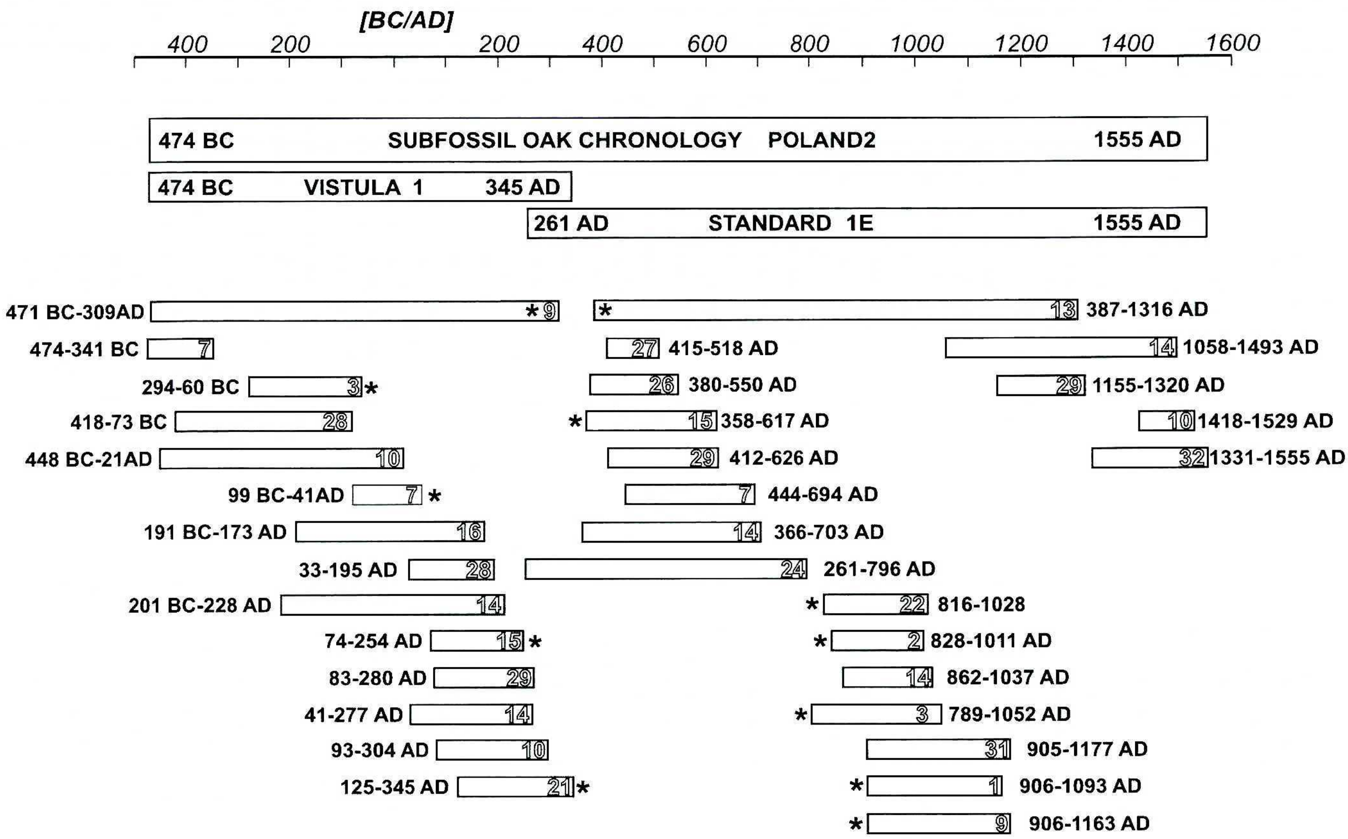

Fig. 2. Construction of the subfossil oak chronology for southern Poland. Blocks represent regional chronologies VISTULA1 and STANDARD 1E and site chronologies forming them (site numbers as in Fig. 1). Asterisks mark new or recently extended site chronologies.

questionable cases the dated sequences were averaged and included into the standard; such procedure increased the quality of the latter. On the other hand, when any correlation with the standards could not be observed, the produced floating chronologies were compared with other, not dated sequences of subfossil oaks (hoping for identification of synchronous positions) and eventually dated with the radiocarbon method. It should be noted that mutual comparison of chronologies, instead of individual curves, facilitated correlation and at the same confirmed correctness of matching. In cases of long enough (at least 300-year) and robust local chronologies, produced from over ten individual sequences, there were chances of their absolute dating through teleconnection with chronologies for southern Germany.

Radiocarbon analyses were also made for individual samples with the highest numbers of growth rings (over 200). Such trees may be considered as pointers, possibly helpful in future to place some following samples on the time scale.

DEVELOPMENT OF STANDARD CHRONOLOGY POLAND2 (474 BC–1555 AD)

The standard chronology POLAND2 was constructed in the first half of the 1990s on the basis of over 300 sequences (Krąpiec 1996b). It is sufficiently replicated at its whole length, almost always containing over ten sequences (maximum up to 79 ones), and only in the mid-fourth century AD consisting of four sequences. Most of the local chronologies and individual patterns produced during the last few years of research cover the last 2500 years. They permitted for better definition of the standard chronologies and completing them with new local sequences, predominantly from the basin of the Odra river, which was a new quality in the up-to-now collected materials (Fig. 2). Results of dating of individual samples, and produced local chronologies are briefly presented below.

Przewóz

The gravel pit in Przewóz is located on the right bank of the Nysa Łużycka river, around 3 km south from the centre of village. From dredged subfossil trunks 16 oak slices and one pine slice were taken for analyses. On the basis of 14 contemporary sequences a local chronology, covering the period 906–1093 AD, was constructed (Fig. 3). It displays very high similarity to the Lower Silesia chronology (t=8.5) and to the black oak standard for southern Poland (t=5.5). All analysed trunks were devoid of sapwood, and traces of action of materials transported by the river indicate their redeposition.

Gryżyce

In the Gravel Mine Gryżyce, situated at the right bank of the Bóbr river, five samples were taken from lifted oak trunks. Two samples enabled construction of 183-year average pattern GRYAA1, covering the period 828–1011 AD. The trees were felled after 958 AD (sample GRY2) and in 1011 AD (sample GRY1). Another oak trunk GRY3, containing 334 growth rings, was dated to the period 172 BC–

PRZEWÓZ (PRWAA1)

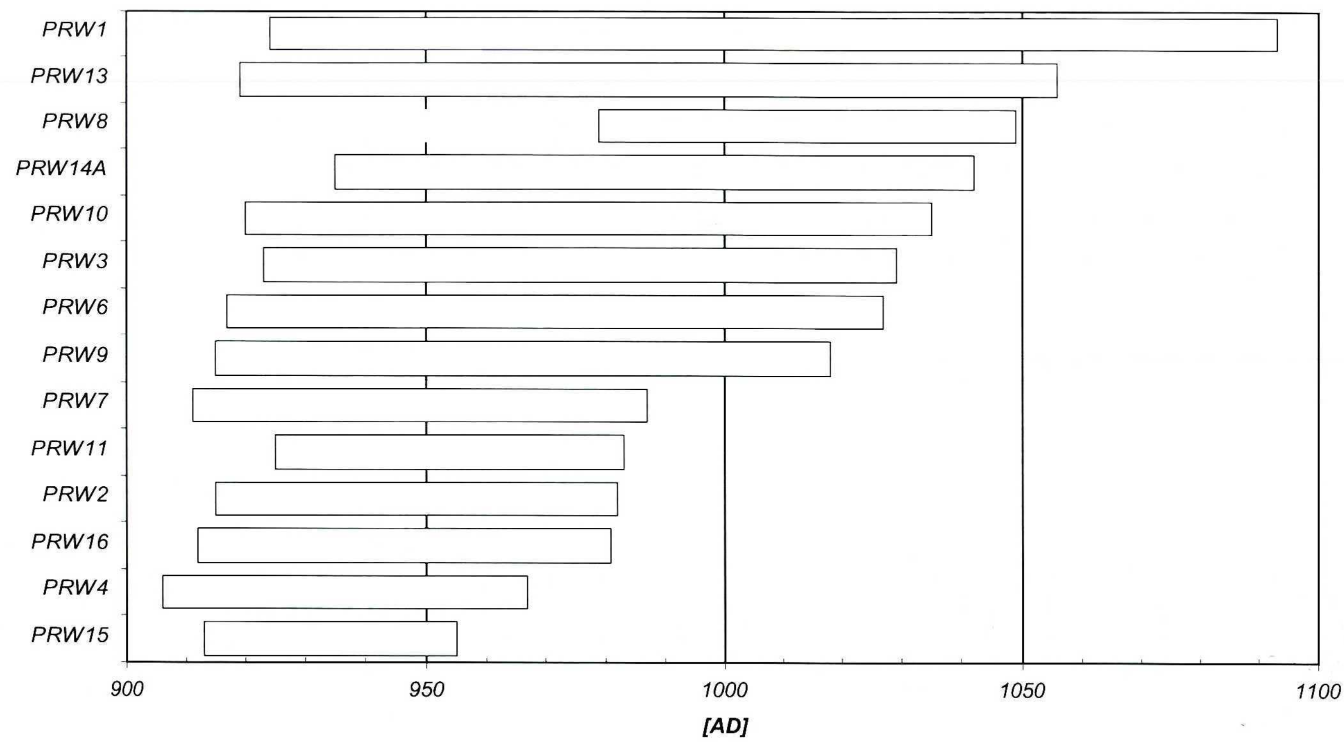

Fig. 3. Dendrochronological dating of annual growth sequences of subfossil oak trunks from Przewóz, defining the site chronology PRWAA1.

161 AD. The analysed sequence exhibited equal similarity to both southern Poland standard and Becker's (1982) chronology (t=5).

Trzebień-Olszna

From a gravel pit located on the left bank of the Bóbr river in the village Olszna 25 oak samples were taken. Two local chronologies were then produced from sequences displaying, respectively, high mutual similarities. The first one, based on five samples 235-year TROLA1, covers the period 294–60 BC (Fig. 4). This chronology exhibits higher similarity to the chronology for southern Germany (t=7.4) than to the southern Poland standard (t=4.5). The second local chronology, 264-year TROLA2 (Fig. 5), was based on another five samples. It was absolutely dates against the Lower Silesia chronology based on historic timbers (t=7.9) and against the southern Poland standard (t=5.1).

Dwory

Four oak trunks dug out at work led at the water threshold Dwory (Krąpiec 1992) were sampled for dendrochronological analysis. Three of them defined the chronology DS_3, spanning the years 99 BC–41 AD (Fig. 6). The remaining sample D1, representing early mediaeval trunk, was dated to the years 829–939 AD.

TRZEBIEŃ-OLSZNA (TROLA1)

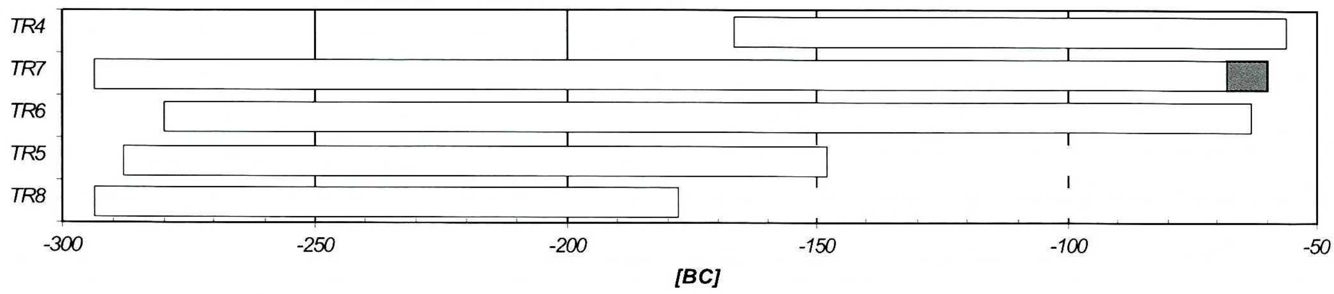

Fig. 4. Site chronology TROLA1 based on subfossil oak trunks from the gravel pit Trzebień-Olszna (sapwood was dark hatched).

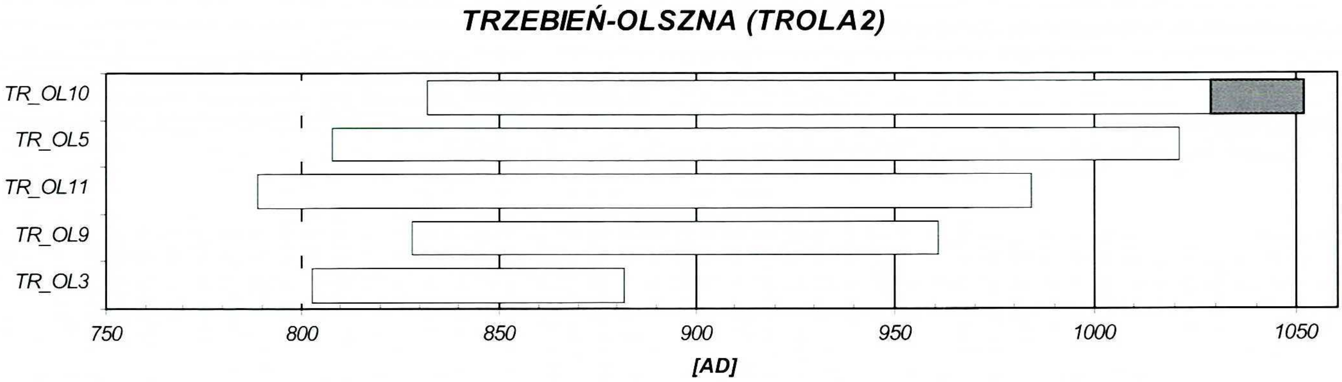

Fig. 5. Correlation diagram of annual growth sequences of oak trunks defining the site chronology TROLA2, gravel pit Trzebień-Olszna (sapwood was dark hatched).

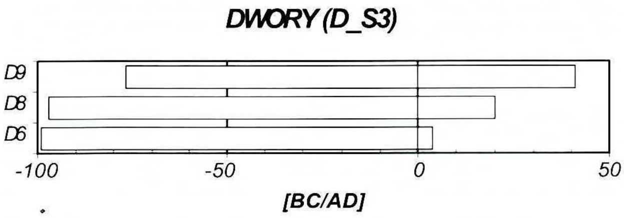

Fig. 6. Dendrochronological dating of growth sequences of oaks from Dwory, defining the site chronology D_S3.

Podolsze

During large earthworks connected with construction of the water threshold Podolsze (Krąpiec 1992) several tens of trunks of black oaks were lifted from alluvial sediments of Vistula river and 70 of them were sampled. It turned out that several oaks grew in Laten and Roman periods. They defined the chronology P_AA2 spanning the period 471 BC-309 AD (Fig. 7). Lack of bark and sapwood indicates redeposition of the analysed trunks. Younger trunks occurred in Podolsze only rarely. Three of them were used for construction of the chronology P_A6 dated to the years 906–1163 AD (Fig. 8).

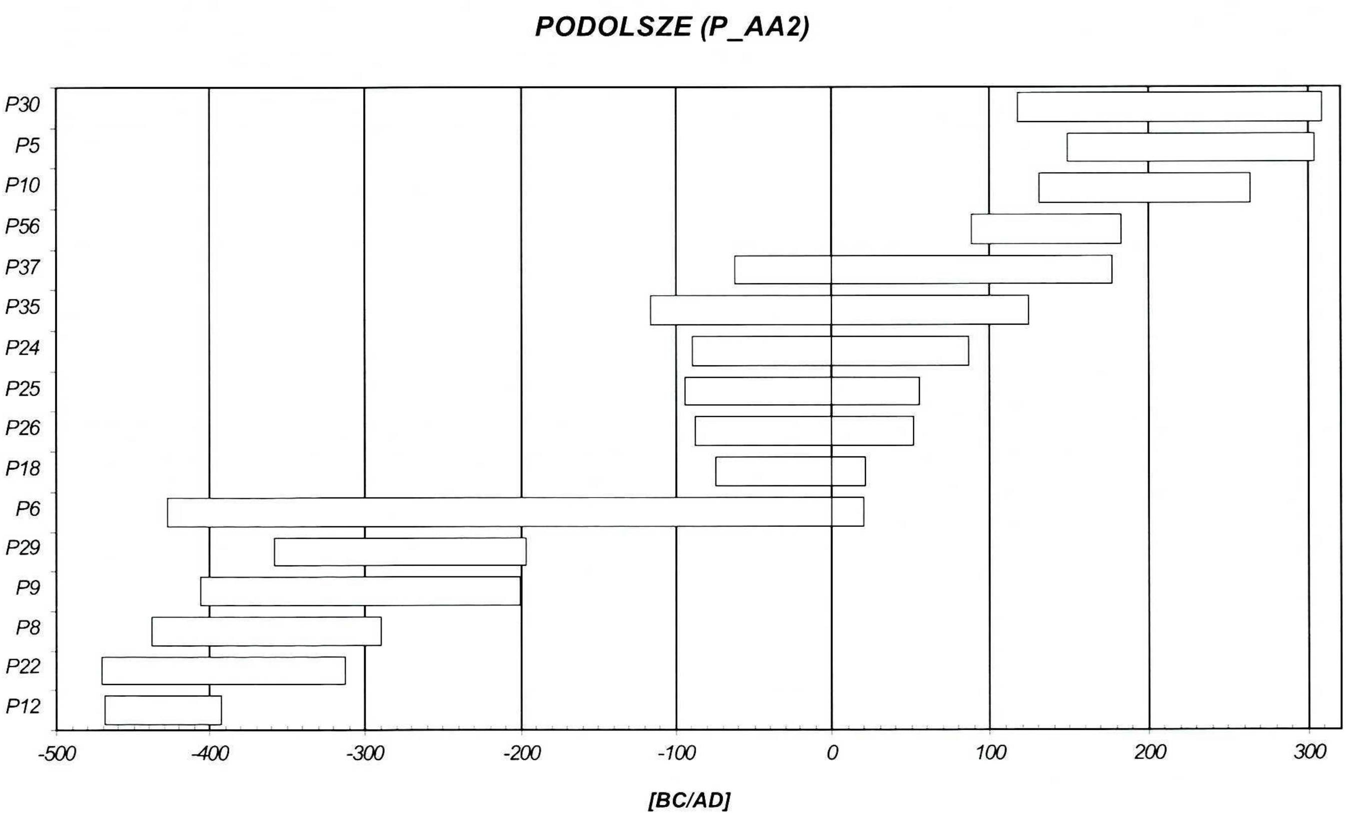

Fig. 7. Dendrochronological dating of annual growth sequences of oak trunks from Podolsze, forming the local chronology P_AA2.

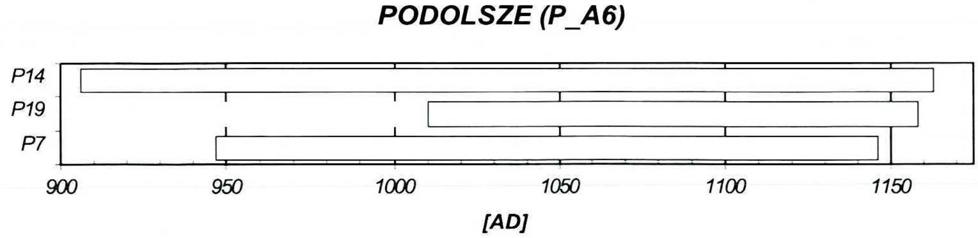

Fig. 8. Site chronology P_A6 produced from subfossil oak trunks from Podolsze.

Kujawy

From earthworks beneath the sewage plant in Cracow–Kujawy (Kalicki, Krąpiec 1992) 96 oak trunks were sampled during earlier research. At the present studies the author gained access to the two biggest trunks, purchased earlier by artisans, and he could sample stored planks. It transpired that their growth sequences enabled construction of local chronology of extraordinary length, not only in Poland but in Europe as well. It covers the period of almost one thousand years, from 387 to 1316 AD (Fig. 9).

Branice

From the gravel pit Przylasek Rusiecki in Branice (Kalicki, Krąpiec 1991a) five oak trunks, containing from over 150 to 337 growth rings, were sampled. The oldest of them was dated to the years 366–703 AD (B96), and the remaining four to the years 1173–1437 AD (B100), 1281–1444 AD (B99), 1256–1470 AD (B98), and 1157–1493 AD (B97), respectively.

Wolica

From the gravel pit in Wolica (Kalicki, Krąpiec 1995b) 115 black oaks were sampled. Collecting of so many samples was possible due to the traditional method of exploitation as well as kind help of the owner and the staff of the mine. Care of optimal usage of exploited materials brought about necessity of dredging and lifting of all trunks buried in the deposit. Great majority of the subfossil oaks were felled in the years 440–620 AD (Fig. 10) and they were added to the earlier defined chronology WAA2 (Krąpiec 1996b). Trees from that period are common in other sites as well, which proves existence of a phase of intensified river activity at that time (Starkel *et al.* 1996).

Among trunks from the last 2000 years there were also encountered oaks which felled in the first half of the third century. They enabled extension of the chronology WAA5, actually covering the period 74–254 AD (Fig. 11).

Machów

At liquidation of the sulphur mine in Machów oak trunks were encountered during work at an escarpment of the open pit. Eight samples taken for the research appeared to be of the same age as some earlier analysed trunks from alluvial sediments exposed in this mine (Krąpiec 1996b). All samples from Machów were used for construction of the local chronology M_A1 covering the period 816–1028 AD (Fig. 12).

Radymno

In the gravel pit Radymno situated on the right bank of the San river 15 trunks of subfossil oaks were sampled. Two samples were used for construction of chronology RDAA1A absolutely dated to the years 125–345 AD (Fig. 13).

Remaining sites

From the remaining sites individual trunks, originating from various time intervals of the last 2500 years, were dated. Particular attention deserves oak trunk exposed in the Botanical Garden of Jagiellonian University in Cracow. This oak, lifted at the end of the 1950s from the bed of Vistula river near the Premonstratensian monastery in Cracow, thank to the effort of Prof. Szafer was taken to the Garden and stored there. It is one of the first of Polish black oaks dated with ^{14}C to 1775 ± 280 BP (Środoń 1980). The growth pattern of this trunk consists of 268 rings representing the years 170 BC-98 AD. Lack of sapwood does not allow for accurate dating of the tree felling, which is only estimated to the turn of the first and second decade of the second century AD.

Somewhat older oak was lifted in Przeciszów during work connected with regulation of the river Vistula. The tree grew in the period 372–88 BC. To the Roman period was dated trunk dredged and lifted from the bed of Vistula river in Witów (186–253 AD). Significantly younger were samples of subfossil oaks from gravel pits in the valley of Wisłoka (Wróblowa 904–981 AD and Klecie 1132–1235 AD), and from Nasiłów in the Vistula valley near Puławy (1436–1505 AD).

NEW SUBFOSSIL OAK CHRONOLOGY C_3000E (1795–612 BC)

Samples of subfossil oaks, taken from sites in the Vistula river valley (Wolica, Grabie and Podolsze) and from alluvia of the Odra river in Wrocław during the last three years, enabled construction of the new 1184-year chronology C_3000E (Fig. 14). The chronology also included earlier analysed samples from gravel pits in Branice (Krąpiec 1992) and Grabiny (Krąpiec 1996b) and from earthworks led in Niedary (Gębica, Krąpiec 1993) and at river threshold "Kościuszko" near Bielany in Cracow (Krąpiec 1992). It was dated to the years 1795 BC–612 BC through teleconnection with Becker's chronology for southern Germany (1993) (t=7.7) and Leuschner's and Delorme's chronology for central Germany (1988) (t=6.8).

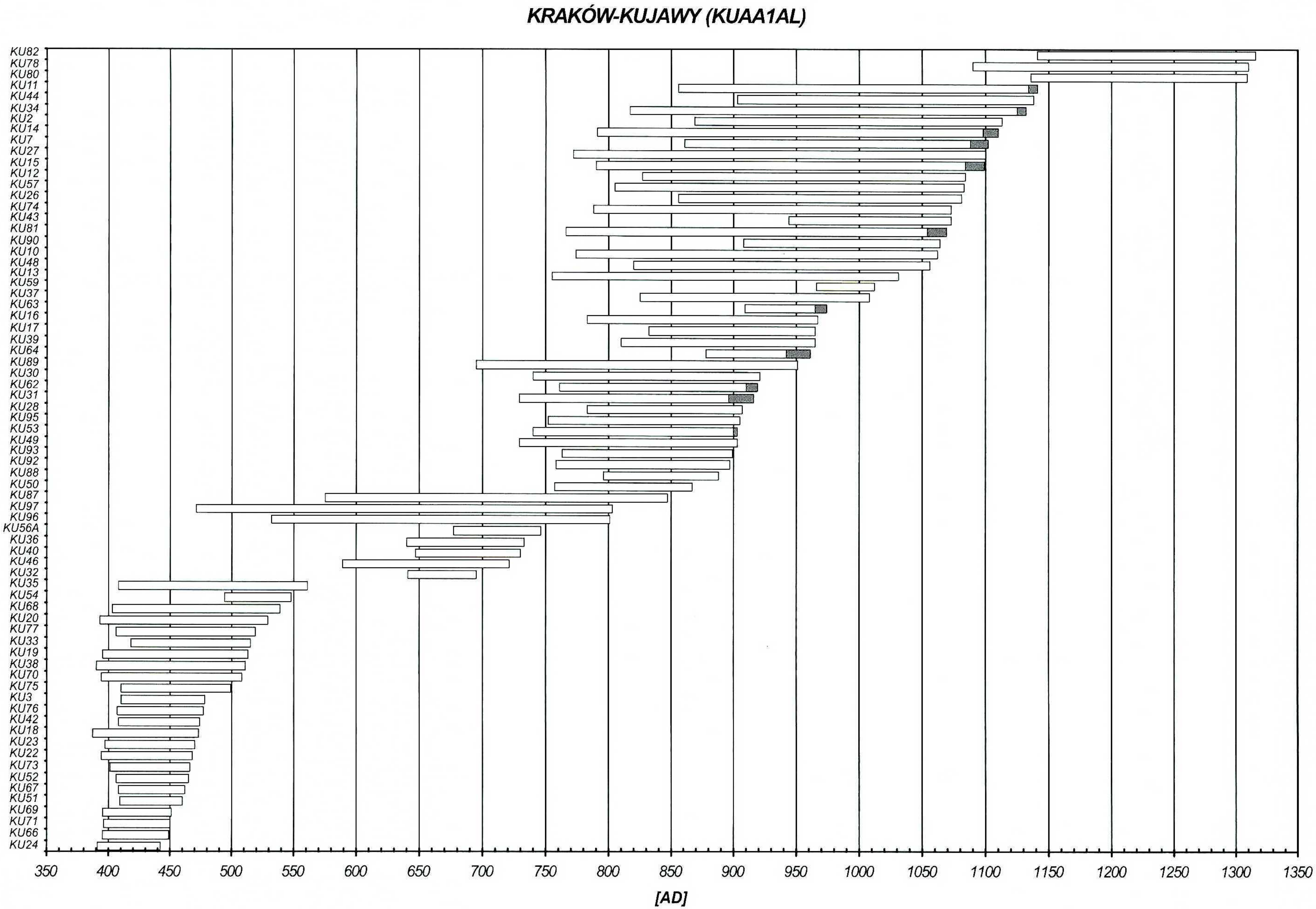

Fig. 9. Dendrochronological dating of annual growth sequences of oaks from the site Kujawy, forming the chronology KUAA1AL (387–1316 AD).

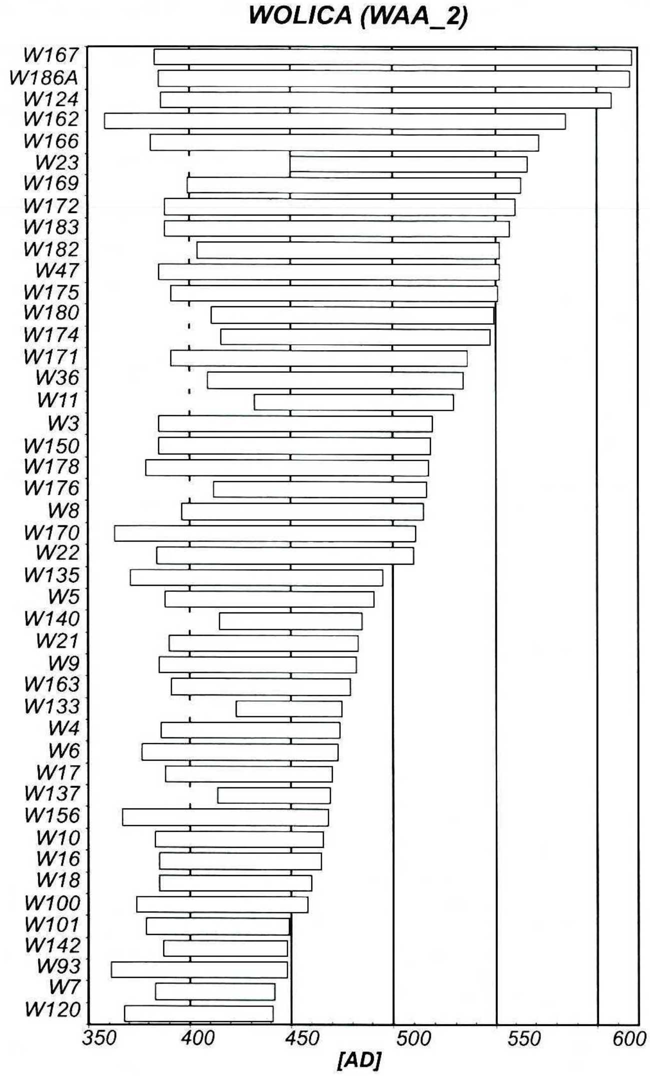

Fig. 10. Correlation diagram of annual growth sequences of oak trunks from the gravel pit Wolica, defining the site chronology WAA_2.

Second Millennium BC Chronologies

Particularly important for construction of the standard C_3000E were chronologies based on oak trunks from the gravel pit in Grabie. Alluvial sediments exploited there had been deposited in a zone of a palaeomeander of the river Vistula, cut off in the middle of the 19th century (Kalicki, Krąpiec 1991b). Great majority of 70 samples analysed dendrochronologically represented redeposited trunks, older than those from the neighbouring sites: Cracow-Kujawy and Branice (Kalicki, Krąpiec 1992, Krąpiec 1992, 1996b). Most numerous were trunks defining the chronology GAA_1U (24 samples). Particularly interesting was the oak trunk containing 448 heartwood rings (sample G21). Thanks to its pattern and those measured at the two other huge trunks of over 300-year-old oaks (G67 and G70A) it was possible to join two generations of oaks into a single sequence (Fig. 15). Its older part was produced from 14 trunks accumulated in alluvia in the period 1630–1500 BC and the younger one from trees felled between 1300 and 1000 BC. The younger generation of oak trunks from Grabie, forming the floating chronology GA1-2, was extensively presented in one of earlier studies (Krąpiec 1992). Most of growth patterns of contemporaneous oaks from the chronology GA1-2 exhibited zones of extremely narrow, reduced annual growths and traces of extensive damages brought about by floating ice (Krąpiec 1998). These sharp reductions of tree-ring widths, commenced in the year 1160 BC, were most probably related to weather anomalies caused by an eruption of the volcano Hekla 3 (see Baillie 1995). Because of these perturbations of growth sequences they were omitted at construction of the average curve GAA_1U, which for dating purposes should reflect variability of climatic conditions and not local events of extreme character.

Oak timber from the second millennium BC was also encountered among trunks from gravel pits in Wolica and Branice, only a few kilometres from Grabie. On the basis of seven growth patterns the 457-year chronology WA_B6, covering the period 1743–1287 BC (Fig. 16) was defined.

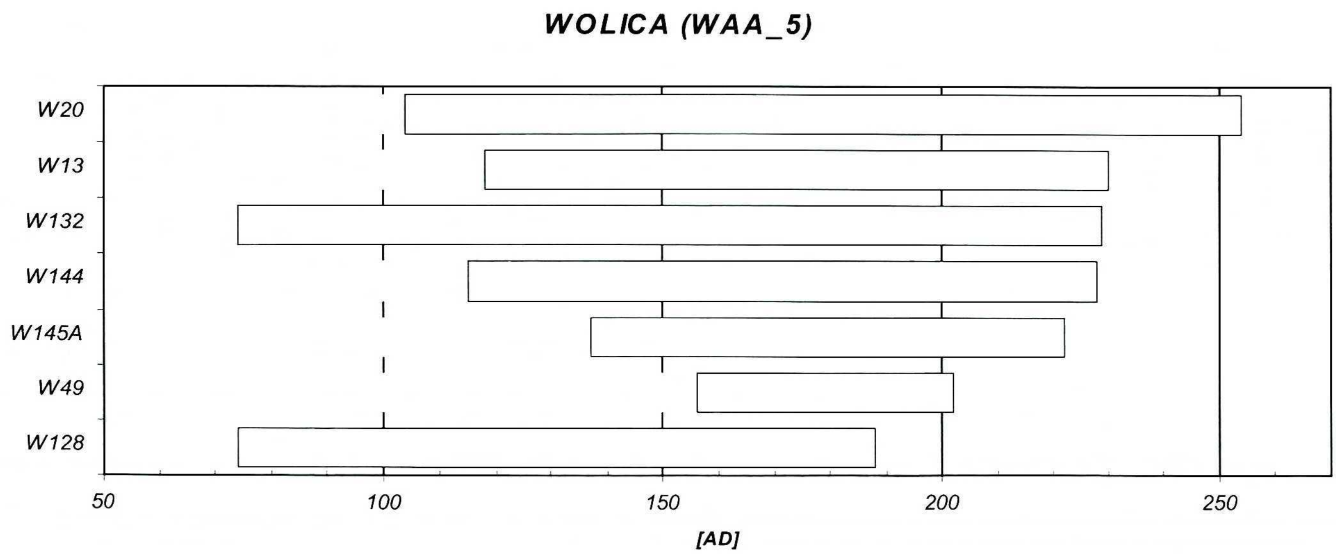

Fig. 11. Site chronology WAA_5 produced from subfossil oak trunks from the gravel pit Wolica.

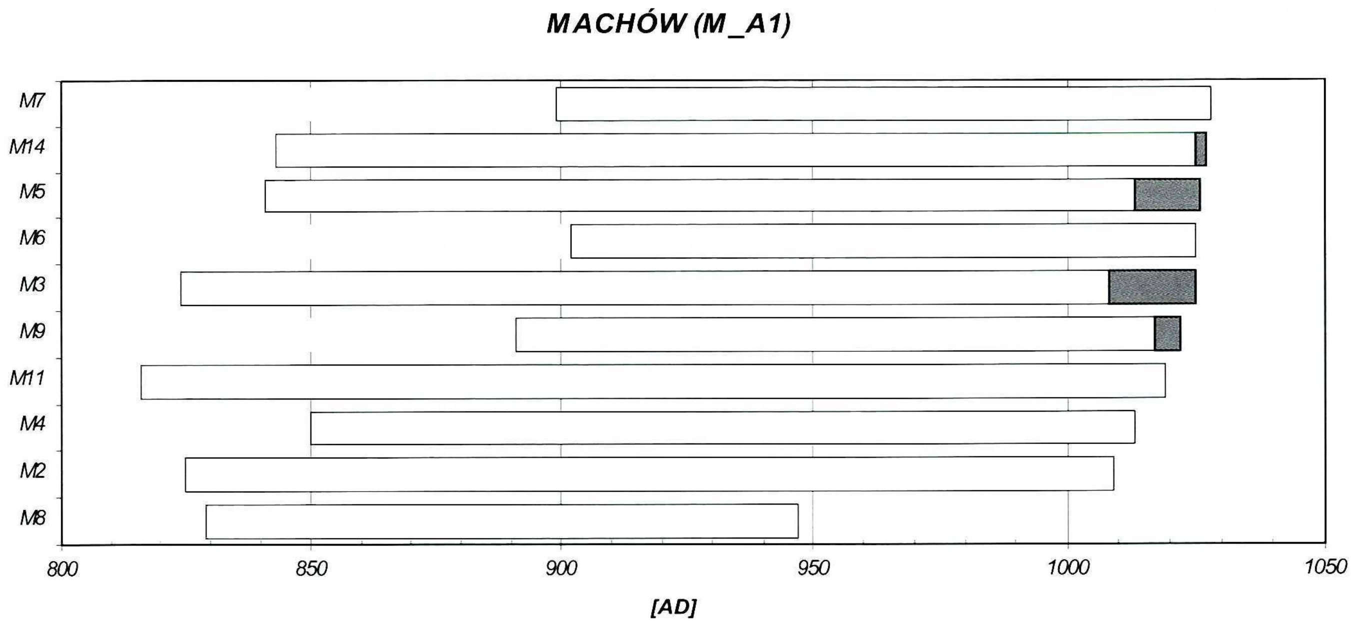

Fig. 12. Correlation diagram of annual growth sequences of black oak trunks from Machów, defining the site chronology M_A1 (sapwood was dark hatched).

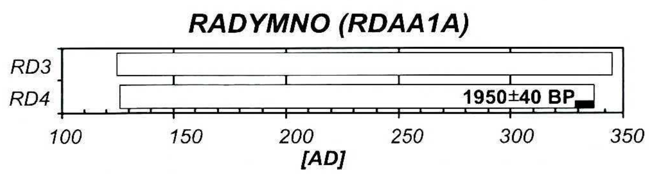

Fig. 13. Dendrochronological dating of annual growth sequences of subfossil oak trunks from the gravel pit Radymno, defining the local chronology RDAA1A.

The backbone of this chronology was the trunk from Branice (sample B15), central and external rings of which were dated with radiocarbon method (Krąpiec 1992). The oaks from Wolica and Branice were felled in a somewhat shorter period than those from Grabie, within the years 1560–1280 BC. It should be noted that among seven accumulated trunks four were felled in the period 1500–1300 BC, during a break of accumulation in the neighbouring Grabie (see Fig. 15). This demonstrates continuous character of the process of felling trees, however, visibly more intensive in humid periods (see Starkel 1995).

High similarity to the earlier presented chronologies is also displayed by the chronology WRQAA1 based on six oak trunks lifted from alluvial deposits of the Odra river during construction of sewage channels at Kasprowicz street in Wrocław (Lorenc, Chlebicki 1993). This 271-year master covers the period 1795–1525 BC (Fig. 17). Radiocarbon dating of external growth rings of the sample WRQ2 gave 3240 ± 50 BP (Gd-7482) and of inner part of the sample WRQ1 - 3650 ± 50 BP (Lod-874) (Krąpiec *et al.* in press). These results seem to indicate that the analysed trees grew in different times, but comparison and matching of tree-ring patterns unequivocally demonstrate their synchronous growth.

Among long (at least 150-year) individual ring patterns of oaks from other investigated sites there were identified two, which show similarity to the chronologies from Grabie, Wolica, Branice, and Wrocław. These are sequences of oak trunks SK1N, containing 468 growth rings, from the river threshold "Kościuszko" and GB4, 202-year long, from the gravel pit Grabiny in the valley of Wisłoka river.

Last Millennium BC Chronologies

The second segment of the standard C-3000E is based on two well documented chronologies from Wolica (WAA_4) and Grabie (GAA_3U). The chronology WAA_4 produced from 11 samples of oak trunks contains 343 growth rings (Fig. 18). This chronology, covering the period 1065–723 BC, made possible connection between other local chronologies. Trees of this chronology, lifted from the gravel pit Wolica in the mid 1990s, at that time enabled construction of the floating chronology WAA4, which was placed on the time scale with radiocarbon dates (Krąpiec 1996b). The trees lifted later permitted to extend this chronology and to correlate it with floating chronologies from Niedary (NA1 and NA2), presented earlier in a separate study (Krąpiec 1992), and with the growth pattern of the oak trunk B68 from the gravel pit in Branice. Correlation values between these sequences are sufficiently high, between t=5.7 and t=8.9. The highest similarity (t=10.9) to the chronology WAA_4 is displayed by the 383-year chronology GAA_3U from Grabie, based on growth sequences of nine oak trunks felled in the period 750–600 BC (Fig. 19). At its initial phase this chronology consisted of three samples (G24, G25 and G26), dredged at the beginning of the 1990s. At that time wood from external growth rings of the trunk G25 was dated with the radiocarbon method, the result being 2290 ± 50 BP (Gd-7309). Lack of similarity between the average sequence produced from the discussed three samples and the southern Poland

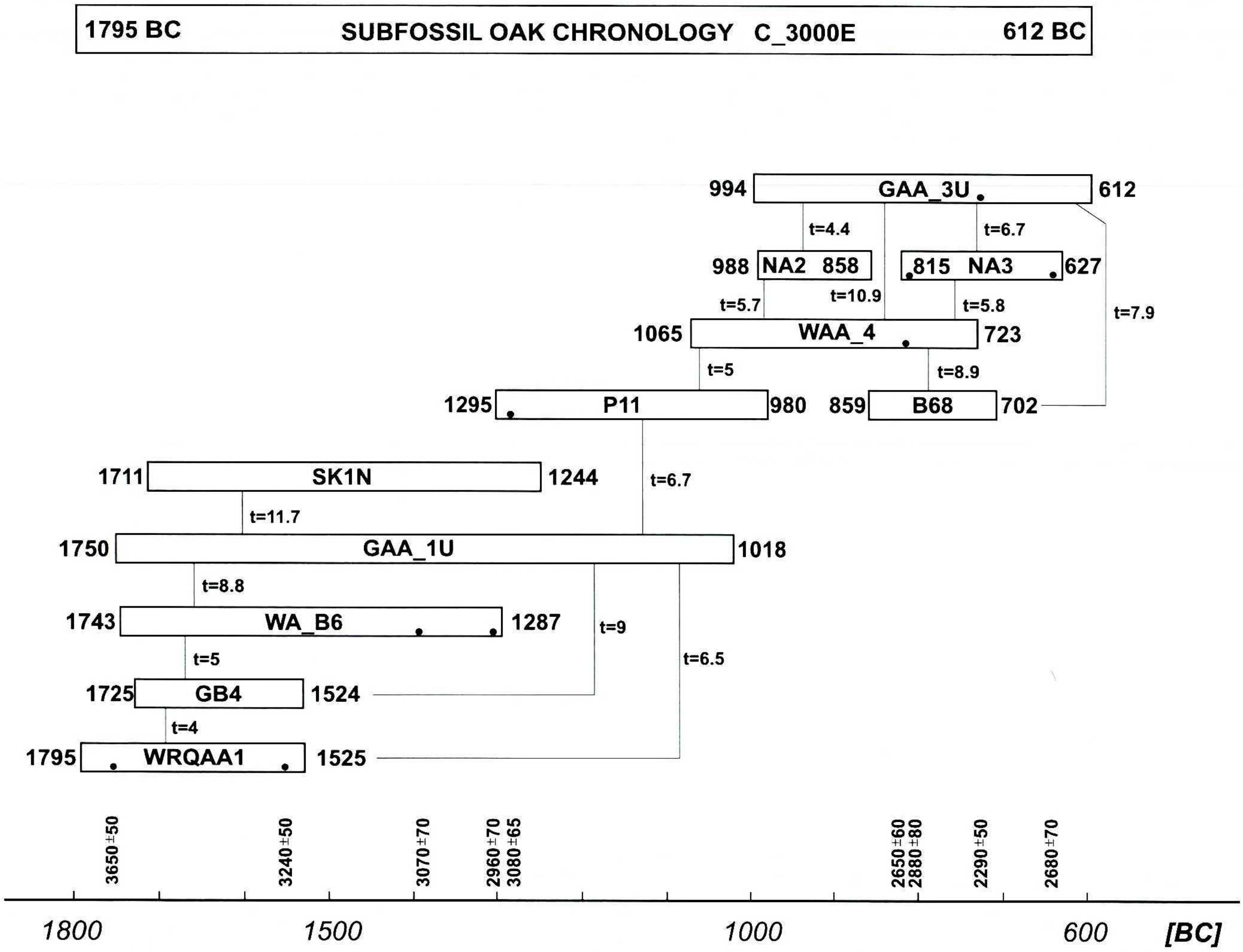

Fig. 14. Construction of the subfossil oak chronology C_3000E. Blocks represent local chronologies and annual growth sequences of individual trunks (GB4, SK1N, P11, B68) defining it. For dendrogram pairs t-values, defining their similarity, are given. Tree-rings sampled for radiocarbon dating are marked with dots, and the dates given below.

standard, extending from recent years back to 474 BC, suggested that the radiocarbon date might be too young. The additional trunks recently lifted in the gravel pit Grabie significantly extended this chronology and demonstrated unequivocally, through correlation with the chronology WAA_4, that the radiocarbon date of the sample G25 had been significantly rejuvenated.

Linkage of the two segments

In unequivocal linkage of the two segments of the chronology C_3000E, named preliminarily as HALL03 (younger) and C_3000 A (older) (Krąpiec *in press*), particularly significant was the oak trunk from Podolsze (laboratory code P11), containing 331 growth rings. It exhibits high similarity to the chronologies GAA_1U (t=6.7) and WAA_4 (t=5). Radiocarbon dating of core rings of this trunk gave 3080 ± 65 PB (Gd-11581), in full agreement with expectations.

The compiled, absolutely dated chronology C_3000E enables verification of radiocarbon dates against exact and accurate dendrochronological dating (see Fig. 14). It should be noted that two of nine results are distinctly biased: significantly older date 3650 ± 50 BP (Lod-874) and considerably younger 2290 ± 50 BP (Gd-7309).

Apart from teleconnection, a reliable test of effectiveness of a newly created chronology is its use as a standard for dating of samples coming from other sites. In the case of the chronology C_3000E this proved to be positive. Against this standard there were dated oak casing of Hallstatt wells from Dębno near Wołów (site 1, 881–748 BC, t=5.3) and from Milejowice in the environs of Wrocław (site 19, 864–664 BC, t=5.9), as well as timbers from a stronghold of Lusatian culture in Wicina near Lubsko (874–607 BC, t=4.9). This demonstrates broad extent of the produced chronology and its usefulness in dating oak sequences from southern Poland.

FLOATING CHRONOLOGIES

Sequences of annual growths of the remaining examined trunks, which did not exhibit similarity to the standard, were compared with one another. As a result of computer correlation and visual matching groups of contemporaneous sequences were identified as floating chronologies, and were

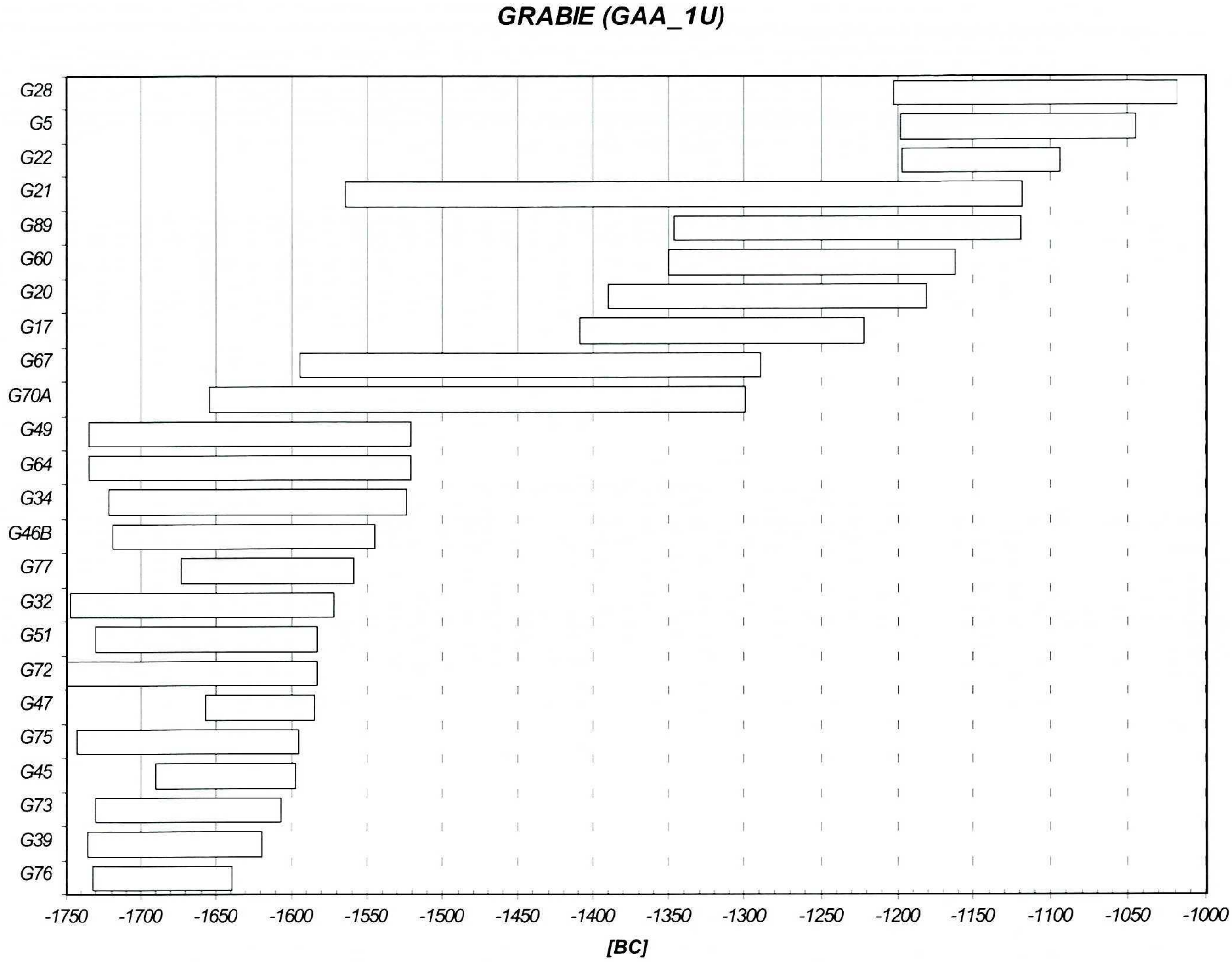

Fig. 15. Correlation diagram of annual growth sequences of black oak trunks from the gravel pit Grabie, defining the site chronology GAA1_U.

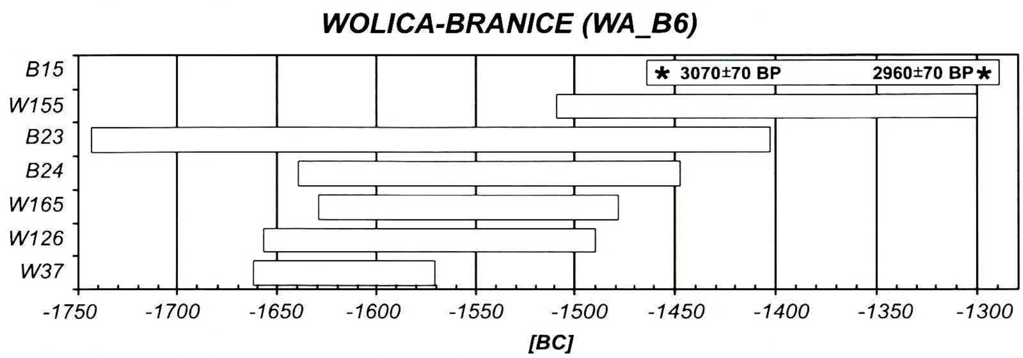

Fig. 16. Dendrochronological dating of annual growth sequences of subfossil oak trunks from the gravel pits Branice and Wolica, defining the local chronology WA_B6.

then dated with the radiocarbon method. It turned out that most of these chronologies represent periods of cooling and humidity (Starkel *et al.* 1996).

Floating chronology KL_ST_1

The chronology KL_ST_1 (Fig. 20) is based on sequences of oak trunks from two gravel pits Strzegocice and Klecie, situated in the valley of the river Wisłoka. Based on two trunks from Strzegocice the mean curve STA2 was produced in 1991. Radiocarbon dating indicated that it could represent Hallstatt period (Krąpiec 1992). In the first half of the 1990s in gravel pit in Klecie four samples were taken from oak trunks, three of which (KL3, 4 and 5) had been at

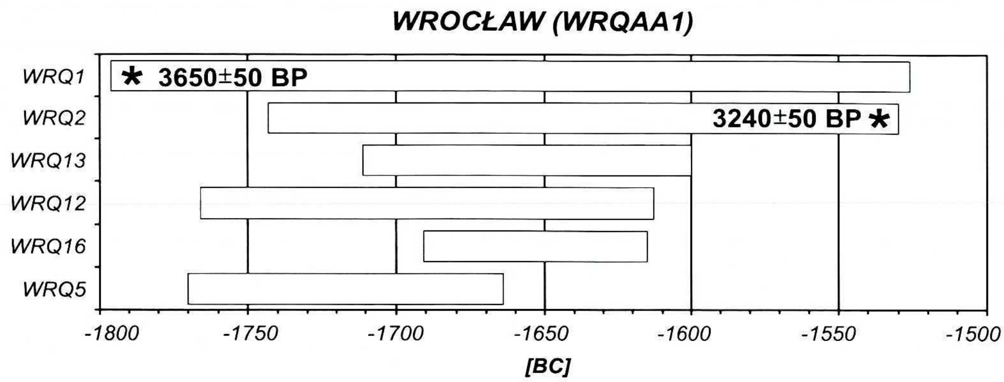

Fig. 17. Dendrochronological dating of annual growth sequences of subfossil oak trunks from the site at Kasprowicz Street in Wrocław, defining the local chronology WRQAA1.

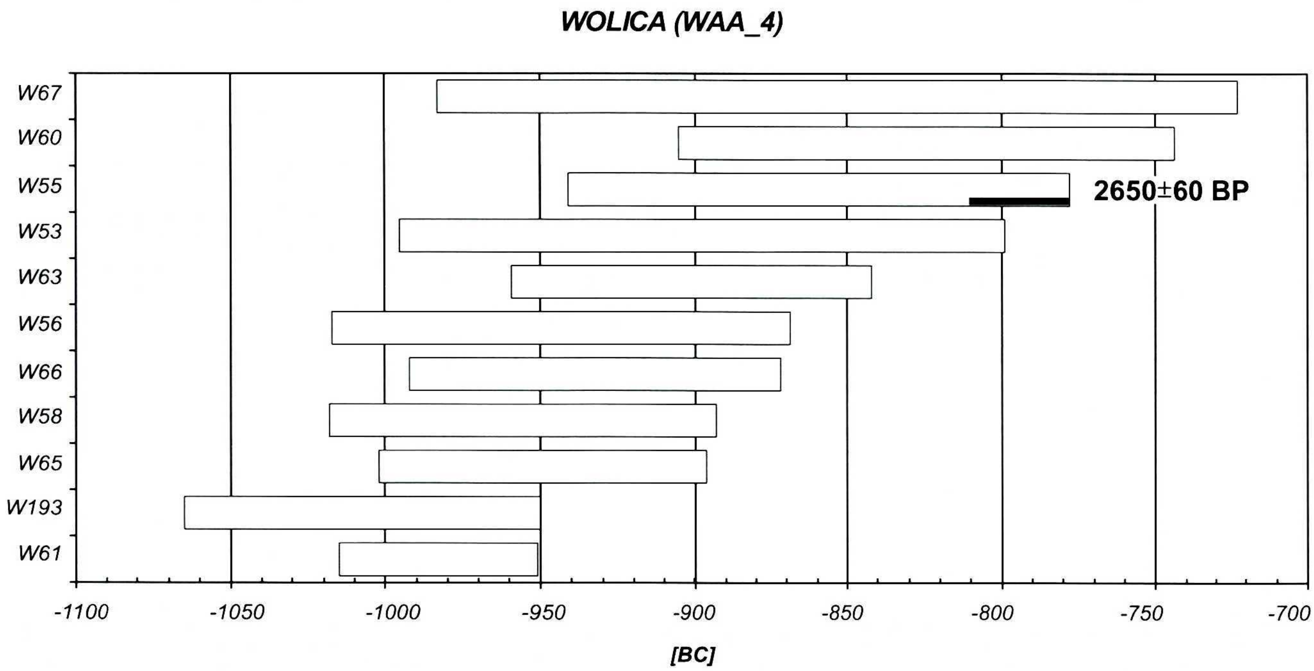

Fig. 18. Site chronology WAA_4 produced from subfossil oak trunks from the gravel pit Wolica.

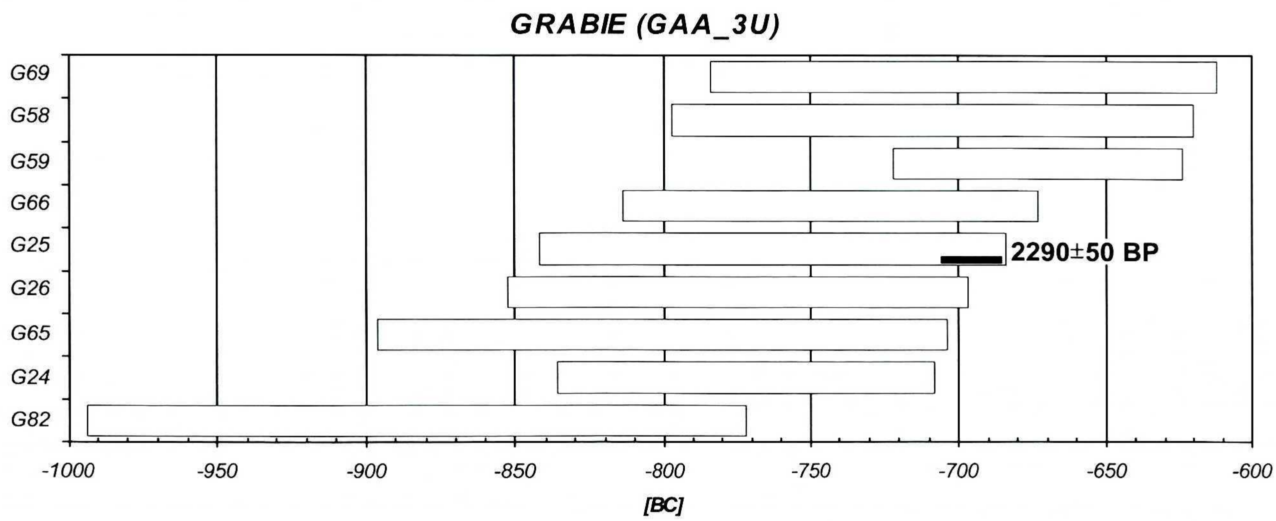

Fig. 19. Correlation diagram of annual growth sequences of black oak trunks from the gravel pit Grabie, defining the site chronology G_AA3U.

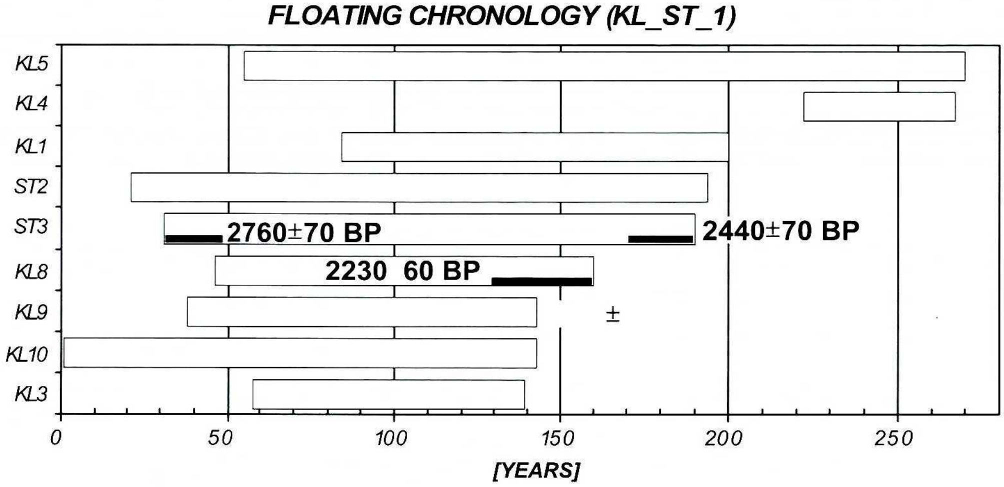

Fig. 20. Floating chronology KL_ST_1 produced from annual growth sequences of oak trunks from the gravel pits Klecie and Strzegocice.

that time erroneously dated to mediaeval times (Krąpiec 1996b). Among subsequently analysed trunks from Klecie, some were recently identified as contemporaneous to those earlier sampled and examined. This extended the mean curve from Klecie. The new sequence from Klecie displays distinct convergence with the chronology STA2 from Strzegocice (t=5.9). Radiocarbon dating of external growth rings of the trunk KL8 gave 2230 ± 60 BP (Gd-12280). This result, although not entirely in agreement with earlier radiocarbon dates of the trunk ST3 (Fig. 20; Krąpiec 1992) suggests, that the chronologies from Klecie and Strzegocice might represent some time interval between absolutely dated patterns

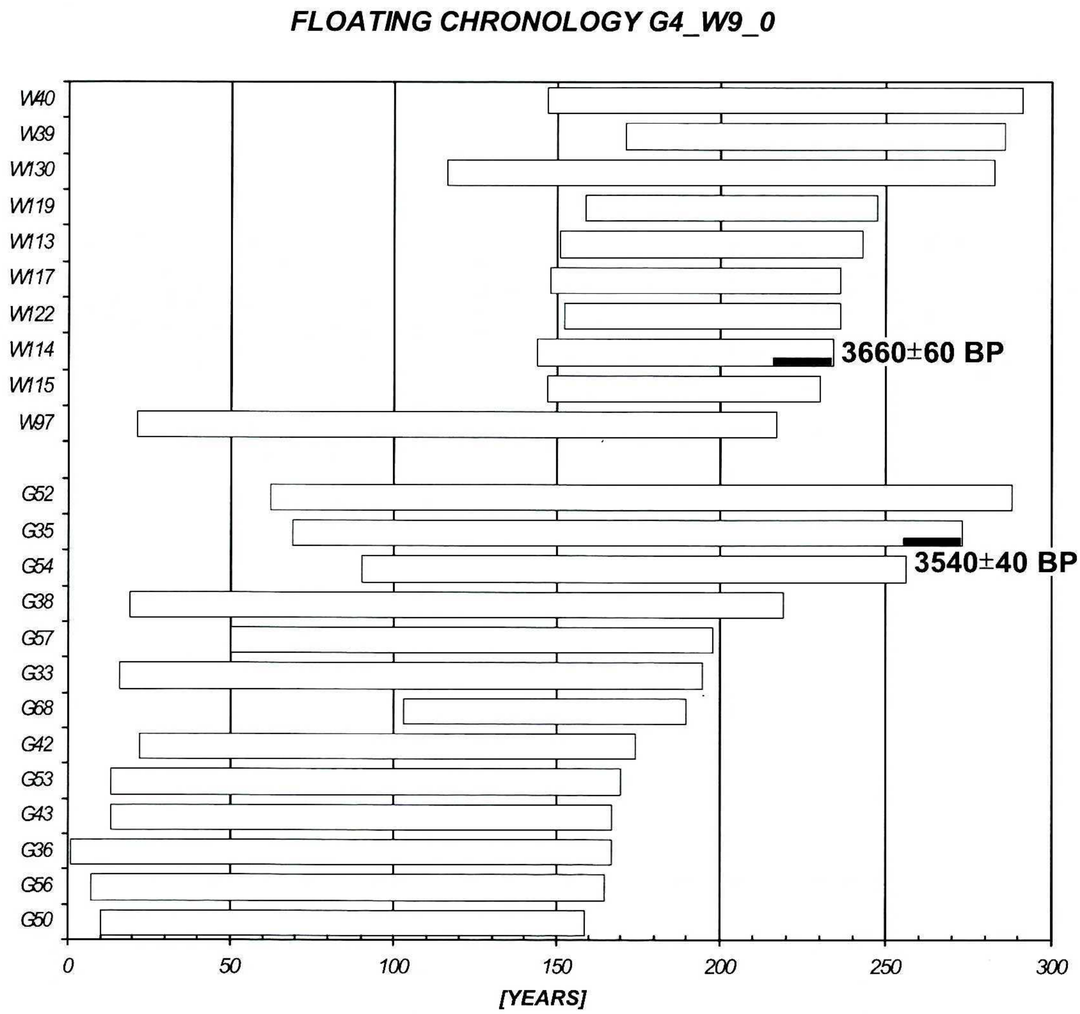

Fig. 21. Floating chronology G4_W9_0 produced from annual growth sequences of oak trunks from the gravel pits Grabie and Wolica.

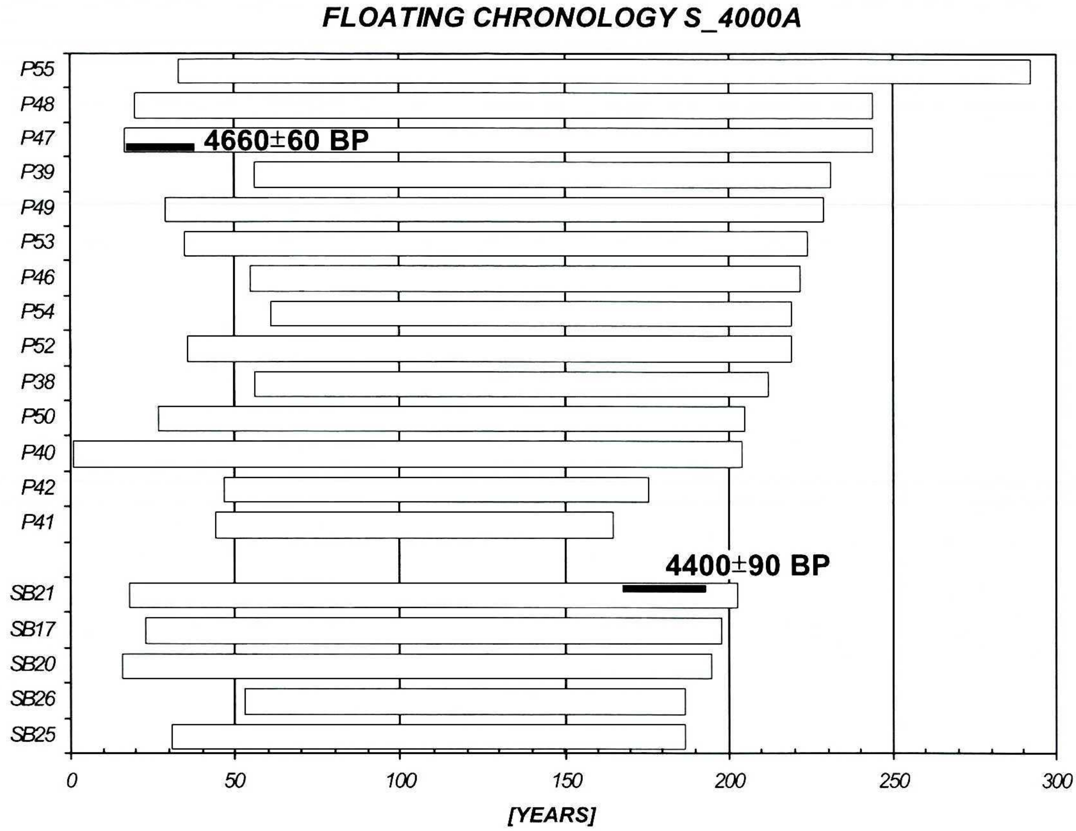

Fig. 22. Floating chronology S_4000A produced from annual growth sequences of oak trunks from the gravel pits Smolice-Zakole B and Podolsze.

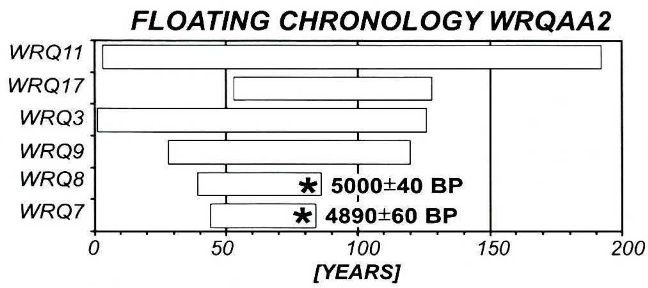

Fig. 23. Floating chronology WRQAA2 produced from annual growth sequences of oak trunks from the site at Kasprowicz Street in Wrocław.

POLAND2 and C_3000E, *i.e.* in the period 612–474 BC. Impossibility of unequivocal matching of the chronology KL_ST_1 to these standards may result from too short periods of overlapping.

Floating chronology G4_W9_0

The chronology G4_W9_0 (Fig. 21) is based on sequences of annual rings of oak trunks from the gravel pits in Wolica and Grabie. The average curve produced from 13 sequences from Grabie displays high similarity to the chronology produced from ten sequences from Wolica (t=6.4), and concordant shapes of both curves do not leave any doubt about synchronism of these sequences. Also radiocarbon dates of external growth rings of two trunks: G35 to 3540 ± 40 BP (Gd-11582) and W114 to 3660 ± 60 BP (Gd-12288) are in full agreement. This allows to suppose that the 291-year long chronology G4_W9_0 has a potential to extend the chronology C3000_E *ca.* 300 years back in time, as ^{14}C analyses indicate that most probably it covers a period between *ca.* 2200 and 1900 BC.

Floating chronology S_4000A

The chronology S_4000A (Fig. 22), older than the above described ones, was compiled on the basis of trunks from the gravel pit Smolice-Zakole B (Krąpiec 1992), and recently sampled trunks from Podolsze. Individual patterns of these trunks display very high convergence (average t=6.3). Great majority of trees started growth in a relatively short time interval of around 50 years. Moreover, they were felled in a comparably short period. Radiocarbon dating of inner rings of the trunk P47 from Podolsze (4660 ± 60 BP – Gd-11656) is in agreement with earlier dating of the trunk SB25 – 4400 ± 90 BP (Krąpiec 1992). These dates allow to suppose that the compiled chronology represents the period *ca.* 3400–3100 BC.

Floating chronology WRQAA2

Among black oak trunks from Kasprowicz Street in Wrocław (Lorenc, Chlebicki 1993) six samples exhibit contemporaneous growth sequences, defining a 192-year chronology (Fig. 23). Radiocarbon dating of external rings of two trunks: WRQ8 to 5000 ± 40 BP and WRQ7 to 4890 ± 60 BP

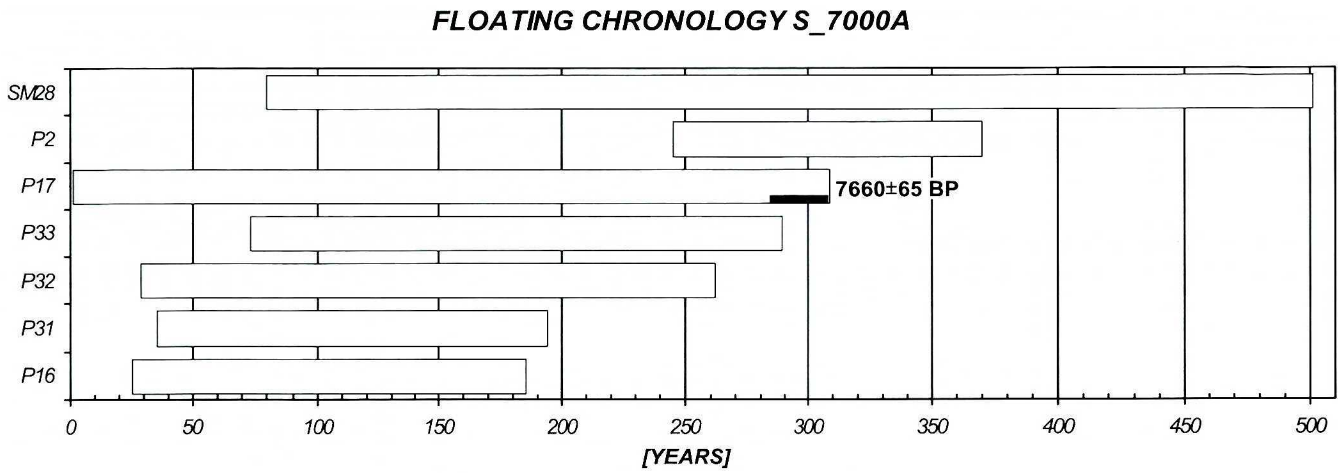

Fig. 24. Floating chronology S_7000A produced from annual growth sequences of oak trunks from the gravel pits Smolice-Zakole A and Podolsze.

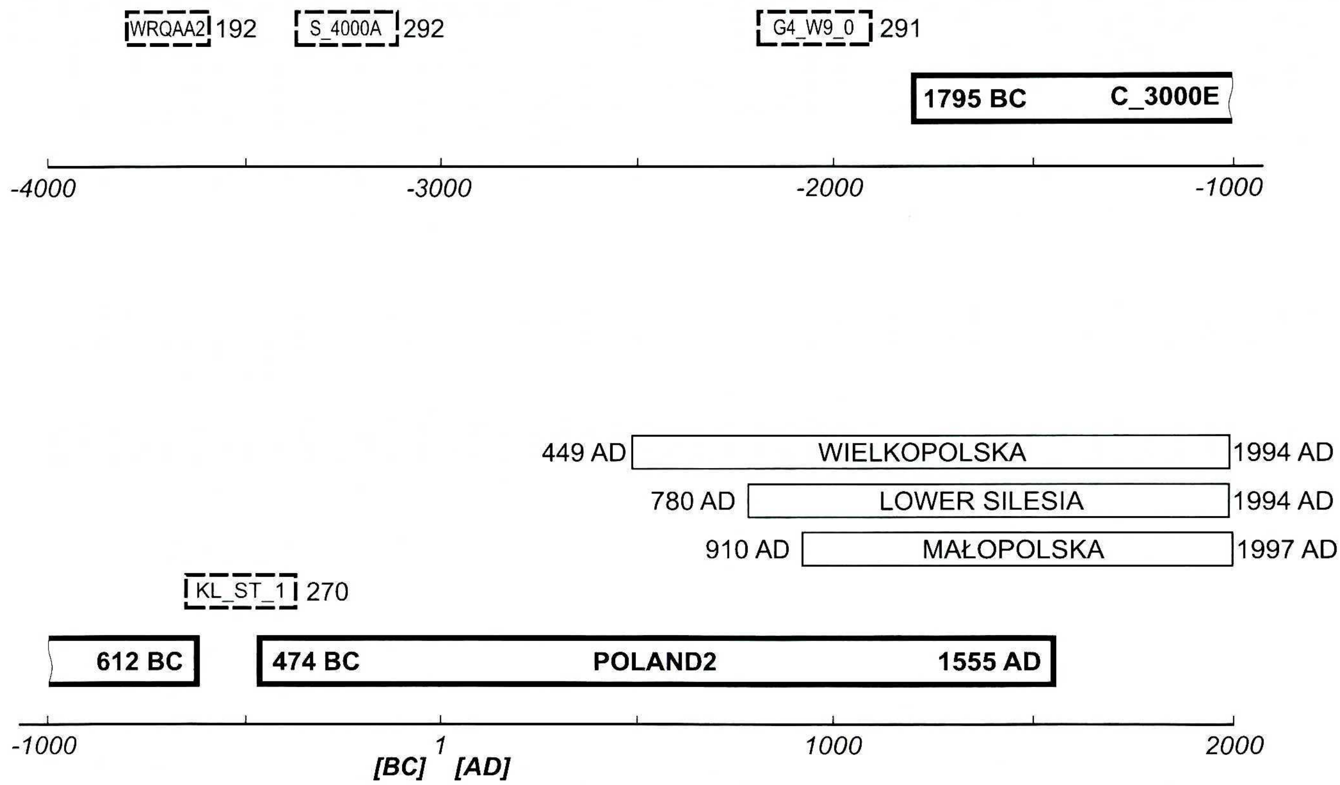

Fig. 25. Standard and floating chronologies produced from subfossil oak trunks from river alluvial sediments and regional chronologies (Małopolska, Lower Silesia and Wielkopolska) based on living trees, monuments of wooden architecture and archaeological timbers (state of the research in 2001).

(Krąpiec *et al.* in print) suggests that the chronology represents the time interval *ca.* 3800–3600 BC.

Floating chronology S_7000A

The backbone of the chronology S_7000A is the oak SM28 from the gravel pit Smolice-Zakole A, one of the oldest and one of the longest growing (over 460 years, 449 preserved heartwood rings) oaks in Poland. According to ^{14}C date the supposed time of felling the tree was determined to *ca.* 6200 BC (Kuc, Krąpiec 1994). Among the trunks from Podolsze dendrograms of six ones were clearly convergent with the sequence of SM28. They constitute the 502-year chronology S_7000A (Fig. 24). Dating of external rings of the sample P17 to 7660 ± 65 BP (Gd-11584) confirmed earlier results, indicating that the chronology most probably covers the period *ca.* 6650–6150 BC.

CONCLUSIONS

Dendrochronological analyses of 970 samples of black oaks, hitherto carried out, allowed for defining of two standard chronologies covering the years: 1795 BC–612 BC and 474 BC–1555 AD, as well as floating chronologies for the approximate periods 6650–6150 BC, 3800–3600, 3400–3100, 2200–1900 BC, and 670–400 BC (Fig. 25). Attempts of absolute dating of the floating chronologies against south German standards were, unfortunately, unsuccessful.

The produced chronologies practically fully enable dating of oak growth sequences from southern Poland coming from the last 4000 years. Taking into account floating chronologies and individual oak samples from the time interval 4000–2000 BC, dated with the radiocarbon method, further extension of the standard chronologies by *ca.* 2000 years back in time seems to be possible in the future.

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