Palaeoecological study on the Holocene valley development of the River Main, southern Germany

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Tree-ring studies carried out on subfossil oak trunk deposits within the Holocene valley fills of the River Main can reconstruct phases of increased fluvial activities. These phases have been dated on the base of two absolutely tree-ring dated chronologies and in addition by ^{14}C-datings of eleven floating tree-ring series of subfossil oaks.

Geological-pedological investigations reveal an alternation between increased and reduced fluvial activity during the Holocene.

Periods of increased gravel redeposition are dated by dendrochronology, and by ^{14}C and cultural findings. Increased fluvial activity becomes more frequent towards Modern Times with culminations in the Middle Atlantic, the Subboreal, the Iron-Roman Age, the Main Middle Ages till earliest Modern Times, and in the last century.

On the sequence of Holocene river deposits there developed specific soil types as indicators for the age of the river deposits since the Last Glacial.

Among other palaeoecological results an important finding is the correlation between tree-ring width, flood-loam sedimentation, and soil development.

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This report is the result of several years of joint investigation of Holocene river sediments and subfossil oak trunks buried in them in the valleys of southern Central Europe. The geological-pedological studies carried out by W. Schirmer should achieve an insight into the Holocene valley development and its dependence on the changing activity of the rivers. A prerequisite for this was the working out of an accurate stratigraphy of the Holocene river deposits. The tree-ring analyses of the subfossil oak-trunks (so-called *Rannen*) of the Main valley, carried out by B. Becker, is a subproject of the long-term task of constructing a complete tree-ring sequence of oak covering the Holocene. It is also intended that the correlation between the development of the Holocene riverine forests, and the characteristic palaeoecological changes of the flood plains, should be more closely examined.

That the focal point of interest within the river courses dealt with jointly by the authors is situated just on the upper and middle course of the River Main, is in one sense connected with the fact that, at this point, favourable exposure conditions prevail for the geological investigation. The gravel pits, from which trunks are continually being dredged out, lie in a close sequence along the valley and permit a close-set investigation of the sediments in cross-section and longitudinal profile. In Fig. 1 and Table 1, all gravel pits are listed from which subfossil trunk layers have been investigated. The geological investigations, however, are based on an even greater number of exposures. In several of the exposures, it is also possible to obtain an insight into the entire vertical profile of the valley fill, as at these localities the ground-water is pumped out down to the base of the gravel fill, to facilitate gravel quarrying.

The Main trunk layers are of importance for tree-ring analysis, too. They are situated broadly in the centre of the Danube, Rhine, and Weser river systems, within which several German tree-ring laboratories are working on subfossil oaks (e.g. Becker, Delorme & Schmidt 1977). Within this area, however, regional differences in the tree-ring patterns are already becoming inconveniently obvious. Crossdating

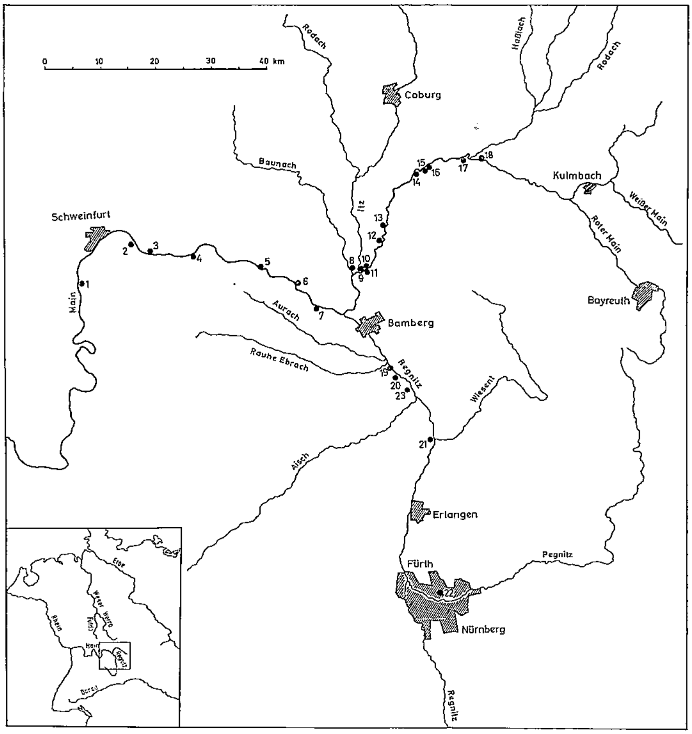

Fig. 1. Localites of subfossil trunk layers in the Main and Regnitz valleys.

of subfossil oak tree-ring patterns succeed over greater distances only through stepwise correlation of neighbouring river areas. Therefore the River Main served, for example, as a bridging member in the successful correlations of subfossil tree-ring series from the River Danube to the Fulda and Werra (Becker, Delorme & Schmidt 1977).

Local observations dealing with the Holocene valley of the Upper- and Middle-Main are available in over 50 publications. Statements which could contribute towards the knowledge of the Holocene valley development are to be found above all in Jakob (1956). Jakob gathered numerous observations about *Rannen* (subfossil tree-trunks) in the Main deposits around Bamberg. According to their height within the gravels, he distinguished two *Rannen* horizons. The origin of these horizons he interpreted in accordance with the ideas of Graul & Groschopf (1952) as catastrophic events during which riverine forests of former, lower situated valley floors were buried by gravels. An extensive statistical material gathered by him, consisting of historical records and cultural finds, accumulates statistically in definite periods. For this reason, Jakob believed he had found the cultural remains of gravel-covered valley floors and that the two *Rannen* horizons could be attributed to the end of the Burial Urn Age, about 800 B.C., and to the Middle Ages.

Körber (1962) delimited cartographically the Holocene valley-filling as 'later lower Low Terrace' in the entire Main valley. Later, on different map sheets, covering the Upper Main and Regnitz valley, this entity was subdivided into two to three terraces: a 'front terrace' (Early Holocene), a later Holocene terrace, and the 'valley filling' (in a sense of youngest alluvions) (Hoffmann 1970; Janetzko & Roloff 1970; Koschel 1970; Lang 1970). For determining these different Holocene terraces, these authors used Jakob's datings of the *Rannen* horizons, beginning with the end of the Subboreal, in various ways.

Principal features of Holocene valley development of the River Main

Tree-ring analysis of the subfossil trunk layers

Findings of buried trunks in our valley fillings must have been known for a long time as special names have been created for them.

Subfossil trees from river gravels in southern Germany are known as *Rannen* (e.g. Jakob 1956); in Upper Austria they are described as *Raner* (Neweklowski 1964). Most of these trunks buried in gravel and sand are oaks, *Quercus sessiliflora* SAL. or *Qu. robur* L. These two species unfortunately cannot be separated distinctly by their wood anatomy (see Huber, Holdheide & Raack 1941). Only in rare cases trunks of other riverine tree species have been found such as ash (*Fraxinus exelsior* L.), alder (*Alnus glutinosa* L.), elm (*Ulmus* sp.), poplar (*Populus* sp.), willow (*Salix* sp.), beech (*Fagus sylvatica* L.) and birch (*Betula* sp.). The subfossil oaks referred to in the following with the name *Rannen* attain diameters of up to one and a half metres. Their state of preservation after a several thousand year repose in ground-water is sometimes so good that today the wood is used for making furniture. The characteristic black colouring of the outer trunk sections, earning them the name *Mooreichen* (swamp oak), is due to a chemical reaction of the hard wood, which has

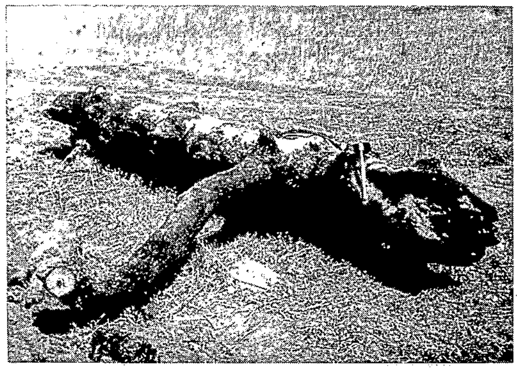

Fig. 2. Well preserved oak *Ranne* with branch. Gravel pit Breitengüßbach. Foto: W. Schirmer 3.5.73.

Table 1. Localities of Holocene *Rannen* layers on the Main-valley.

Number in the map	Locality	Total number of trunks	Workshop title of the layers
1	Heidenfeld	not yet processed	
2	Schonungen	15	Main 3, 10
3	Gädheim	21	Main 1, 2, 3, 4, 6, 16
4	Obertheres	23	Main 3, 5
5	Limbach	5	Main 1, 6, 8
6	Stettfeld	13	Main 1, 6, 7
7	Viereth	26	Main 4, 9, 11
8	Baunach	12	Main 1, 8
9	Breitengüßbach I	44	Main 1, 2, 4, 6, 13, 15
10	Breitengüßbach II	28	Main 2, 5, 6, 7, 13, 11
11	Unteroberndorf	16	Main 1
12	Zapfendorf	6	Main 1, 8
13	Ebensfeld	37	Main 1, 2, 3, 6, 8, 11, 13, 16
14	Hausen	7	–
15	Kösten	6	Main 10
16	Lichtenfels	6	Main 3, 5, 10
17	Trieb	43	Main 1, 8
18	Hochstadt	24	Main 1
19	Pettstadt	24	Main 1, 2, 5
20	Erlach	21	Main 1
21	Burk	17	Main 5
22	Nürnberg	4	Main 3
23	Altendorf	13	Main 2, 10

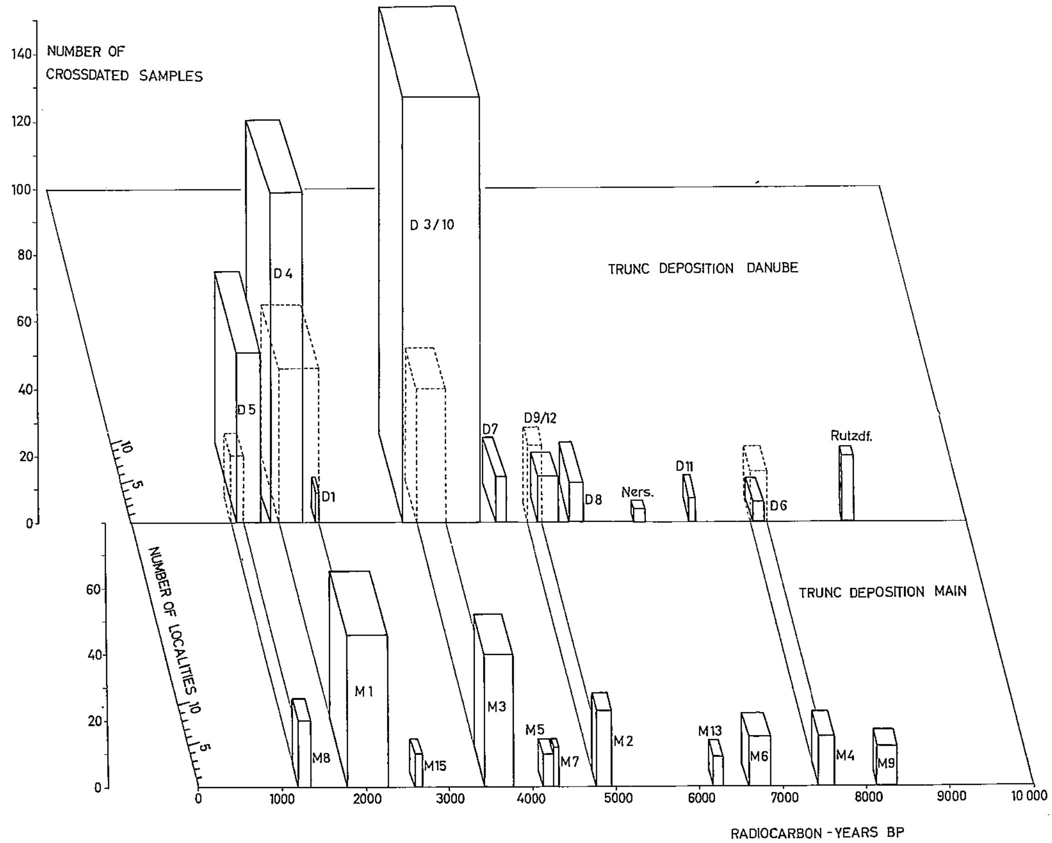

Fig. 3. *Rannen* deposits and their temporal heaping in the Main and Danube valleys. The blocks are constructed on base of the deposition-periods (x-axis), number of cross-dated trunks within each layer (y-axis) and number of localities (z-axis). Cross correlation between the Danube and Main valleys are shown by dotted blocks in the upper part of the diagram.

a high tannic acid content, with iron-bearing ground-water. We use the term 'subfossil' for the structure of these *Rannen* – whose organic substance is still fully preserved – in contrast to fossilized wood, whose original components have been changed, for example, by incoalation or completely replaced by silification.

The deposition of the subfossil trunk layers can be followed along the River Main by means of 213 dated oaks, the tree-ring patterns of which are correlated into 13 determined absolute or floating chronologies. In Fig. 3 the time sequence of death for the *Rannen* layers and their temporal heaps on the River Main and the River Danube are represented in a block diagram form. Table 2 gives additionally all important dates for the Main chronologies, and the terminology used there has also been retained in the text following the Table.

The deposition of eroded riverine forest was obviously a typical and widely spread occurrence during the Holocene valley history. Distinct phases of increased river-activity can be reconstructed by a significant clustering of cross-dated trunks. There does exist a remarkable coincidence of time interval and extent of the down-wash of riverine oaks on the Danube and Main. Nevertheless, the Danube valley, in view of its 640 analysed cross-sections, is considerably better covered than the Main,

Table 2. List of all hitherto dated subfossil trunk layers of the Main-valley.

Work-shop title	Total number of trunks	Dating of the entire tree-ring sequence		Dating of the deposition period		Localities (Table 1)	Total localities	Cross-correlation
Main 1	46	397 BC – 130 AD[a]		226 BC – 130 AD[a]		3, 5, 6, 8, 9, 11, 12, 13, 17–20	12	65.2[c]
Main 2	23	5219	–4759 BP	4936	–4758 BP	3, 10, 13, 19, 23	5	65.3
Main 3	40	3881	–3419 BP[b]	3767	–3419 BP[b]	3, 4, 13, 16, 22	5	64.9
Main 4	16	7753	–7420 BP	7614	–7420 BP	3, 7, 9	3	70.3
Main 5	10	4398	–4119 BP	4251	–4119 BP	4, 10, 16, 19, 21	5	68.3
Main 6	15	7016	–6591 BP	6848	–6591 BP	3, 5, 6, 7, 9, 10, 13	7	63.9
Main 7	12	4580	–4255 BP	4308	–4255 BP	6, 10	2	73.1
Main 8	20	420 AD– 711 AD		559 AD– 711 AD		5, 8, 12, 13, 17	5	61.7
Main 9	12	8518	–8120 BP	8358	–8120 BP	7	1	66.8
Main 10	23	4404	–4105 BP	4300	–4105 BP	2, 15, 16, 23	4	61.3
Main 11	9	8097	–7782 BP	7900	–7782 BP	7, 10, 13	3	64.5
Main 13	9	6480	–6160 BP	6279	–6160 BP	9, 10, 13	3	66.4
Main 15	10	2934	–2595 BP	2682	–2595 BP	9	1	69.2

[a] Dated absolutely by tree-rings.
[b] Calibrated ^{14}C-datings.
[c] Mean of the values of agreement of all cross-dated samples (%).

from which to date 274 samples have been evaluated.

The oldest Main *Rannen* layers date from Boreal and Early Atlantic Times. The successful cross-datings of the tree-ring patterns from these simultaneously (between 7650 and 7400 B.P.) washed-down trees on the Danube and Main provide first indications of the supraregional course of the river-activities even during the Lower Holocene. A decisive change in the history of the valleys can be recognized from a significant increase in trunk numbers at the beginning of the Subboreal. Within a time span extending over some 400 years, trunks have been accumulated beginning at 5100 B.P. on the Danube and at 4900 B.P. on the Main, whose cross-dated tree-ring patterns once again cover the synchronous course on both rivers. The flooding and eroding forest sites along the valleys reached its first zenith during the period between 4160–3240 B.P. on the Danube (First main horizon according to Becker 1973 and 1977). This phase can be followed on the Main by means of 40 cross-dated subfossil oaks in 5 exposures, over the period 3750–3400 B.P.

Following the Bronze Age *Rannen* deposition, a phase of inactivity lasting over more than 1300 years probably occurred. From southern Central Europe there is only one single trunk layer on the Main known to us (M15 = 2680–2590 B.P.). With an average of 300 growth-rings the relatively great age achieved by these oaks implies a purely local interruption of an otherwise undisturbed riverine forest development within the valleys during this time.

About 220 B.C., a renewed phase of flooding began to destroy the riverine forest. This can be reconstructed dendrochronologically by means of 46 cross-dated trunks from 8 exposures along the Main-valley. The deposition of this *Rannen* layer, obviously the most important horizon of Holocene Main valley, extended over some 350 years between 220 B.C.–130 A.D. This period of enforced fluvial activity is simultaneously evident in the Main and Danube area (Second main horizon according to Becker 1973/77). Furthermore, the Iron-Roman Age tree-ring patterns have been dated absolutely, following their successful correlation with the ring-sequences of Roman oak bridges and wood remains of settlements in northern Switzerland and in the River Rhine area (Hollstein 1967; Becker 1977). The growth and death processes of all cross-dated trunks

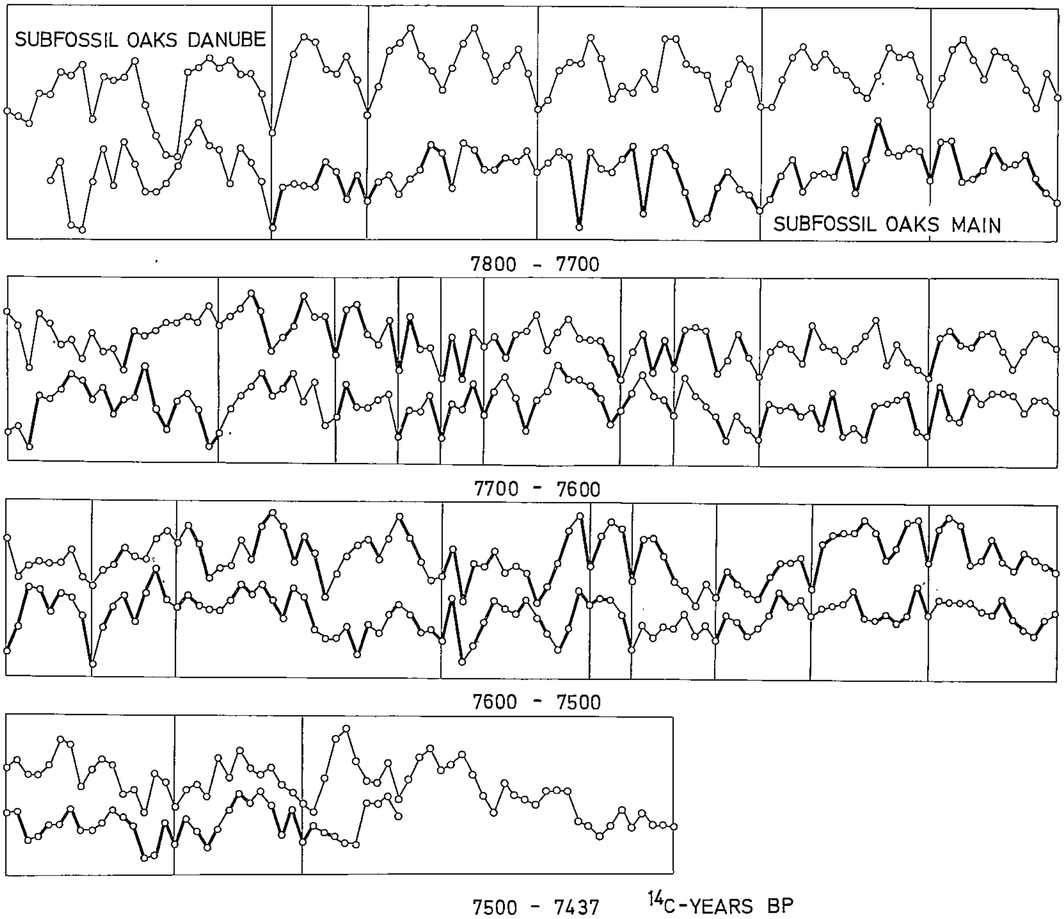

Fig. 4. Tree-ring pattern of the *Rannen* layers Danube 6 – Main 4 7800–7437 B.P. Signature-years (ring-width variations with a value of agreement of more than 80% within all cross-dated samples) are made plain by thick lines in the curves.

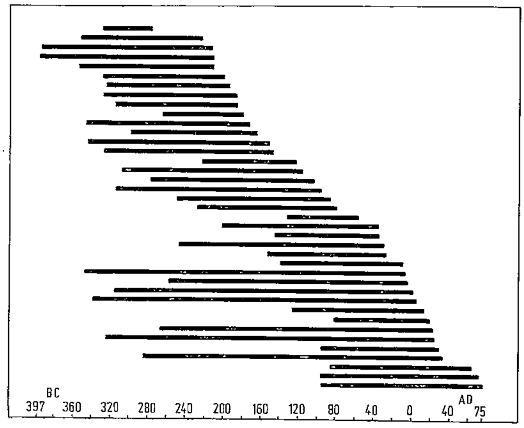

Fig. 5. Growth and death processes of the *Rannen* layer during the Iron-Roman Period in the Main valley. Each block shows one cross-dated trunk; growth starts on the left hand and ends on the right.

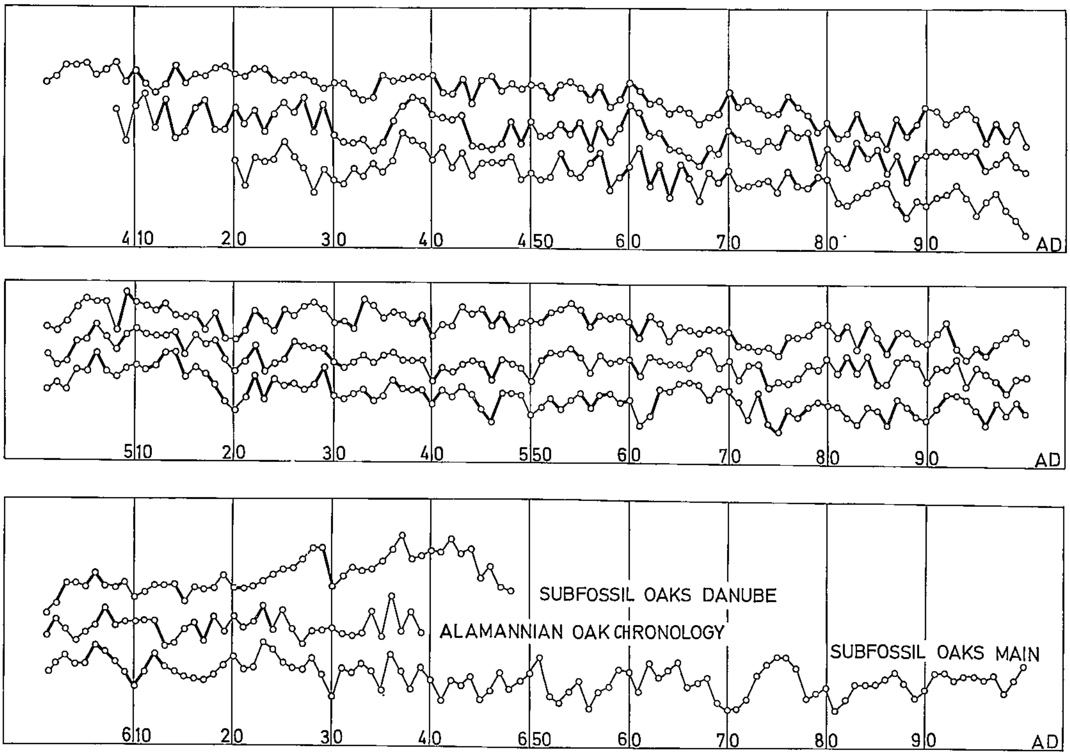

Fig. 6. Tree-ring pattern of Early Middle Ages riverine oaks as well as tree-coffins of the Alamannian Period. The master chronologies are plotted on the absolute time scale from 400–700 A.D. Signature-years are shown by thick lines.

are recorded diagrammatically over the absolute time scale in Fig. 5. Obviously the genesis of this layer is not to be explained by a single catastrophy which overflooded the oak-sites, but rather by a continuous deposition for more than three centuries. A final *Rannen* horizon was established in the Main valley in the Early Middle Ages. The trunks recovered, dating between 560–711 A.D., probably cover only the earlier section of a phase which began on the Danube in 350 A.D. and which led to the creation of the Third main horizon (Becker 1973, 1977).

Even more recent tree-ring data from the Main valley were used in buried Middle- and Late Middle Age pile constructions (Becker & Schirmer, in prep.). They reveal that since the beginning of the 13th century A.D., extensive river-bank building was undertaken in the valley plain to protect cultivated land.

Geological structure of the valley fill and Holocene valley development on the Middle and Upper Main

The Holocene valley fills in Central Europe reveal a geological structure which – corresponding to the orographical and hydrological conditions – differs slightly between the Alpine forelands, the Central Uplands, and the northern German Plains (see Schirmer 1973, 1974). According to this subdivision, the Main is a typical Central Uplands river. Its upper- and middle-course can be regarded as a region of uniform macroclimate which also is free of young tectonics. Therefore, disturbing local tectonic and local climatic influences are not to be expected from the results obtained.

In the valley ground there lies the gravel fill of the Würm Age Low Terrace. On those strips at the edge of the valley floor where its

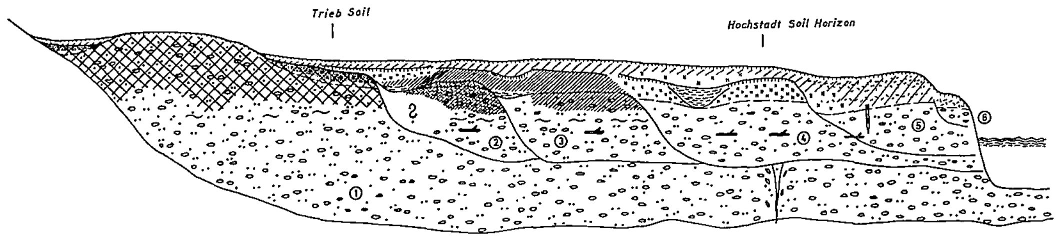

Fig. 7. Schematical cross section of the structure of the valley floor along the Upper Main River.

(1) Würm Age gravel ('Low Terrace') with ice-wedges; in special positions with Trieb Soil on its surface.
(2) Middle Atlantic Age gravel.
(3) Subboreal Age gravel.
(4) Iron-Roman Age gravel with Hochstadt Soil horizon on the top of its flood loam.
(5) Main Middle Ages to Modern Age gravel with pile constructions.
(6) Last century gravel.

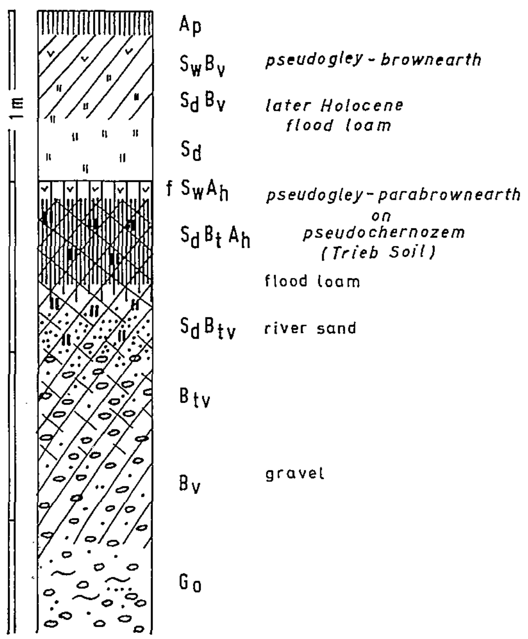

Fig. 8. Generalized section of the early Holocene valley floor with Trieb Soil. Legend see Fig. 7.

surface is still intact, it extends upwards to some ten metres above the present river level. Its thickness extends down to the river level or a little lower. The Holocene deposits are restricted to within this gravel fill: Their surface rises to 5 m above the present river-level. Their base does not extend down to the lower boundary of the Würm gravel, so that below the Holocene gravels Würm gravel is always preserved (see Fig. 7) (Schirmer 1977). Those parts of the Low Terrace which are not covered by Holocene gravels bear a deeply extending para-brown earth. (All soil types mentioned in the following text are floodplain soils, *Auenböden,* that is a soil with a gley horizon at the basis.) At a slightly lower surface covering Late-Glacial deposits a pseudo-chernozem has developed on a floodloam of 0.5–1 m thickness on average (see Fig. 8). Its humus substance revealed a ^{14}C-Age of 7980±110 B.P. (BN. 1801). This soil has been referred as Trieb Soil (Schirmer 1977). It is often present in the valleys of the Central Uplands region. Additional datings from different rivers are ranging in age from the Preboreal up to the Atlantic (see Schirmer 1973: 309).

A subsequent braunification of the pseudochernozem, which penetrates down into the underlying gravel, can be explained by a lowering of the previously higher situated groundwater table during the down-cutting of the river.

The earliest exposed Holocene gravel accumulation on the Main valley is dated by means of a *Rannen* layer to the Atlantic Period (M 13: 6279–6160 B.P.). The deposits have been exposed only rarely. Their thickness extends somewhat over 3 m (see Fig. 9). A 1–2 dm

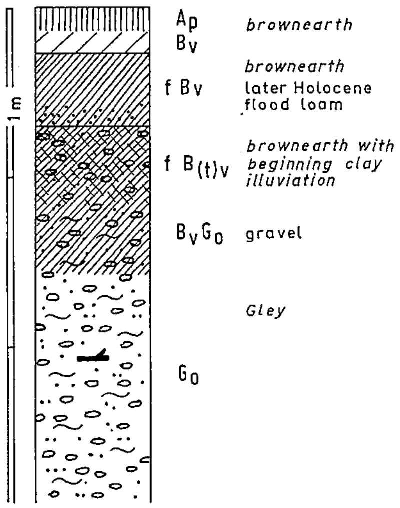

Fig. 9. Simplified section of the Atlantic gravel layer at Ebensfeld. Legend see Fig. 7.

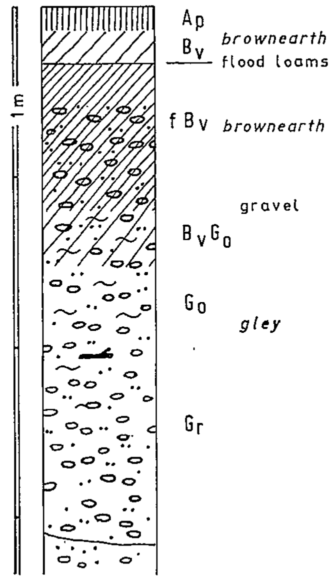

Fig. 10. Simplified section of the Bronze Age gravel layer at Ebensfeld. Legend see Fig. 7.

thick sandy flood loam, covered by later flood loam deposits, is probably the rest of a once thicker, later somewhat eroded flood sediment.

On flood loam and gravel a strong brown earth extending downwards to an average of 1.5 m has developed, which bears light traces of clay illuviation and firmly cements the gravel. Later flood loams are overlying this soil.

From other areas gravel deposits from the Atlantic Period are known only rarely, e.g. on the Erft to the West of Cologne (Schirmer, in prep.), where they were dated due to Banded Ceramic finds and finds from the Rössen Culture.

Since the beginning of the Subboreal, several gravel layers, closer in time to one another, were deposited in the Main valley. According to ^{14}C-dated *Rannen* layers (M2: 4800–4650 B.P. M7: 4290–4255 B.P. M5: 4250–4120 B.P.) they can partly be placed into the early Subboreal. More widely distributed are gravel bodies of the later Subboreal, about the Bronze Age. Nearby Ebensfeld, for example (see Fig. 10), such gravel crops up with a thickness of 4 m. It contains many *Rannen* from chronology Main 3 (sedimentation period 3750–3400 B.P.). Probably all hitherto discovered Subboreal gravel aggradations of the Main valley belong to a continuous accumulation phase, especially since *Rannen* findings on the Danube continually cover the period 4160–3240 B.P. All hitherto known facts concerning the structure of Holocene valley fills show unanimously that on other rivers in southern Central Europe Subboreal gravel deposits are also widely distributed (Schirmer 1973).

The Subboreal gravel of the Main valley shows in its upper part together with its overlying flood loam a strong brown earth. The braunification extends on average to a depth of 1.5 m, but is considerably less intensive than that on the Atlantic gravel. In the overlying beds even younger flood loams follow.

The river history apparently shows, at about the change from Subboreal to Subatlantic – in other words Late Bronze Age to Early Iron Age – a period of decreased fluvial activity. Gravel deposits from this period are known very seldom.

According to the observations to date, the most widely distributed Holocene gravel body on the Main originated during the Late Iron Age and the Early Roman Period. In pits No.

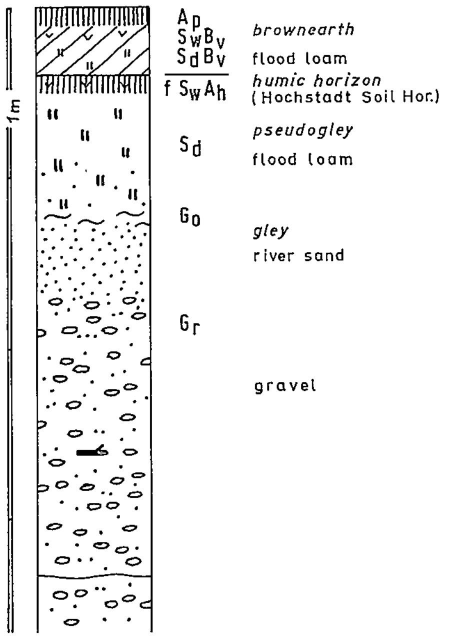

Fig. 11. Generalized section of the Iron-Roman Age gravel layer at Trieb and Hochstadt. Legend see Fig. 7.

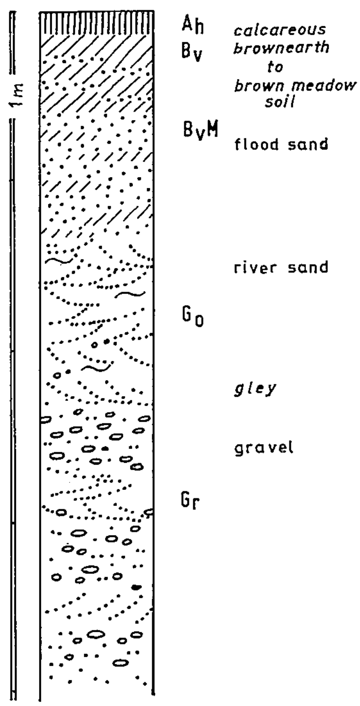

Fig. 12. Section of a Late Middle Ages gravel layer at Viereth. Legend see Fig. 7.

17 and 18 (Hochstadt and Trieb) it attained a thickness of up to 3 m above the Würmian gravel (Fig. 11). By datings of several *Rannen,* which all belong to the Main 1 chronology, a minimum time-span from 220 B.C. until 130 A.D. can be given for the gravel accumulation. In narrower valley sections of the Main, such as that above the mouth of the River Rodach, this gravel covers almost the entire width of the present-day valley. By dating the *Rannen* spread out over a larger area within this gravel it was possible to reconstruct the shifting of the river within the valley (see below).

The Iron-Roman Age gravel body is completed by an approximately 1.5–2 m thick flood loam deposit upon which a weak brown-earth has developed. A buried humus horizon (Hochstadt Soil Horizon) indicates the upper limit of this soil. It is covered by later flood loams. ^{14}C-determinations of the Hochstadt Soil Horizon obtained from charcoal which came from the deeper parts of the humic horizon (Hv 5564: 1440 ± 115 a B.P.), as well as from roots of this soil (Hv 5559: 1285 ± 130, Hv 4279: 1225 ± 85 a, Hv 4691: 1170 ± 60), spread over a period from 400–840 A.D., thus pointing in the main to the Early Middle Ages (Schirmer 1977).

A gravel redeposition dated, however, dendrochronologically by *Rannen* finds of the Main 8 chronology obviously must have occurred in the same span of time. As a spatial relationship of this trunk deposit to the Hochstadt Soil Horizon has not as yet been established and as considerable deviations possibly exist between tree-ring and radiocarbon ages, the exact time-relationship of the Hochstadt Soil Horizon and the Early Middle Ages trunk layer must still remain open.

The latest large gravel accumulation can be attributed to the main Middle Ages up to early Modern Times. So far as observations were possible, the base of this gravel layer which extends up to 4 m in thickness is always cut into older Holocene gravels, but never in Würmian gravel. The Middle Ages gravel contains no *Rannen.* However, ceramic finds (in some cases glazed), tools, and other culture finds provide datings as well as ^{14}C-data of wood remains ranging in time from approx. 1000 to approx. 1500 A.D. In addition, tree-ring data of gravel-covered oak pile constructions with cutting-dates from between 1205 and 1590 A.D. (Becker & Schirmer, in prep.) give evidence for the phase of deposition of this gravel.

The Middle Age gravel is overlaid by a flood loam which covers the valley plain to a great extent and even covers the flood plain of the Early Holocene (see Schirmer 1977). The soil on this flood loam is developed as an allochthonous brown soil with transitional features of an autochthonous soil formation of the brown-earth type (see Fig. 12). A young high-water bed has formed as a margin near the river that lies on average 2–3 m below the Holocene flood plains described so far. A gravel bed, shallow-situated, lies in its underground up to 1 m in thickness overlaying older Holocene gravels. This gravel contains cultural remains from the 19th century as well as examples of *Dreissena polymorpha* (Pallas), a shell that migrated into the Main in the previous century, showing therefore the young age of this deposit (see Schirmer 1977).

Survey of the Main valley development during the Holocene

Fig. 13 shows diagrammatically the development of the Holocene valley on the Upper- and Middle Main. The figure reveals that during the Holocene, periods of relatively fluviatile inactivity alternated with periods of increased fluviatile material redeposition.

The river activity of the ending Late Glacial stabilized during the Holocene. This is expressed by the formation of a pseudo-chernozem (Trieb Soil) upon the Early Holocene flood plain. From the Boreal Period onwards, oak trees near the river banks were eroded and deposited as *Rannen*. The significance of the Early Holocene trunk deposits in respect to the valley history of the Boreal and Early Atlantic cannot exactly be estimated from the present geological findings. After a strong gravel redeposition assignable to the Middle Atlantic Period, the geological findings indicate a relatively undisturbed valley development during the second half of the Atlantic. *Rannen* layers from this period are unknown.

From the beginning of the Subboreal the available findings show a continuously shortening rhythm of increased and reduced lateral erosion and gravel redeposition. Stronger redeposition tendencies occur during the Subboreal up to the Early Bronze Age, and during the Iron and Roman Age.

Whereas Early Middle Age-dated *Rannen* have not yet been connected with gravel deposits, widespread Middle Age gravel deposits and smaller Modern Age sediments could be followed in many sections along the valley.

Detailed findings concerning the *Rannen* deposition and gravel accumulation

Tree-ring data interpretation from subfossil trunk layers applied to fluviatile processes

The tree-ring investigations of *Rannen* must in most cases be carried out on trunks which have been dredged out of the ground-water during gravel quarrying. Their original position within the gravel is therefore largely unknown. As already mentioned, in several exposures of the Upper Main valley the ground-water is lowered to the gravel base for gravel quarrying. In such exposures we could saw off a greater number of trees in situ, and by means of their tree-ring processing, we could obtain data concerning the stratigraphy and the formation of the Holocene valley sediments.

The transfer of the tree-ring data onto the spatiotemporal course of the gravel formation imposes the prerequisite that one can largely exclude the reworking of older trunks and their redeposition in younger gravel bodies. We examined this question in three gravel pits of the Upper Main valley (No. 11, 17, 18, Table 1), in which trunk-bearing faces of the Iron-Roman Age gravel, in some cases more than 100 m in length, are exposed down to the Würmian base. After four years of observation, no remains of older trunk-bearing Holocene gravel could be found anywhere in these pits. During this period the attempt was made to sample the dredged out *Rannen* as completely as possible. The evaluation of the findings gave the following result:

From the 54 tree cross-sections examined, 24 were cross-dated with the Iron-Roman Age *Rannen* layer (M1). From the remaining trunks not a single sample could be correlated with the other tree-ring series from the Main. In consequence, during the course of the four year exploitation in the three exposures, no reworked tree was found. The non-cross-dated trunks represent the portion of samples within a *Rannen* layer that cannot be further processed because the number of growth rings for significant correlation lies either on or under the necessary limit (less than 100 tree-rings).

The probability of a renewed accumulation of *Rannen* that were exposed by erosion is likely to be very small. The depositing of uprooted trees, which for example one can see today on the River Isar in the 'Pupplinger Au' after pronounced high-water, occurs because following the recession of high-water, the trees are caught up on flat gravel banks or in shallow channels. Thereby the roots and larger branches which are buried quickly by underwashing, function as an anchor, with the result

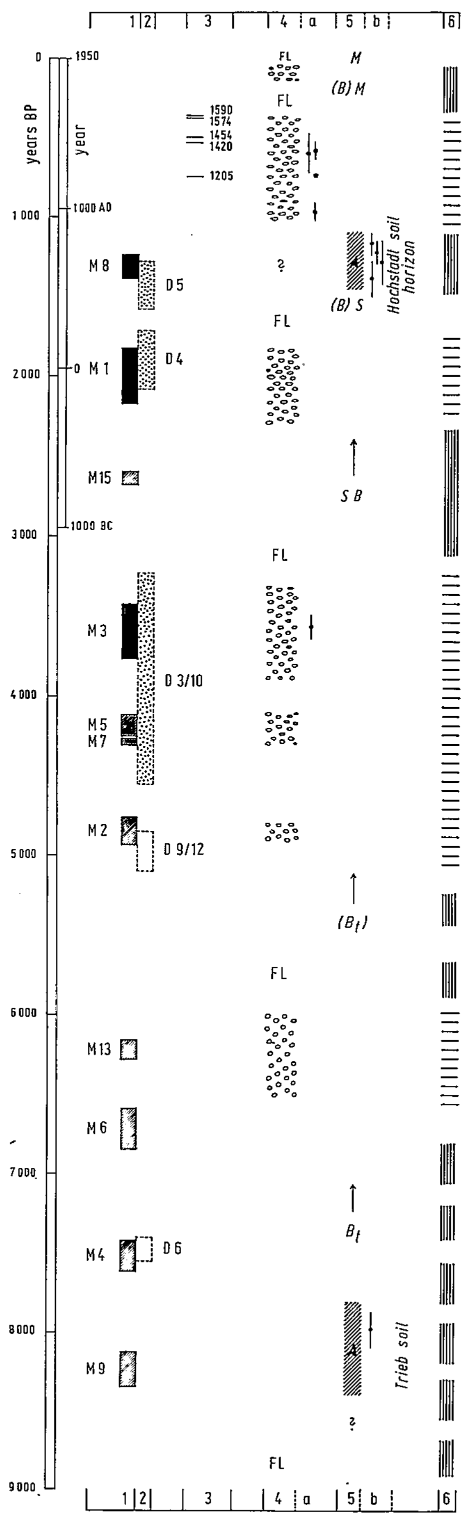

Fig. 13. Diagram of Holocene valley development of the River Main.

Column 1

Black signature: felling dates of tree trunk layers Main 1 and 8 (dendrochronologically dated), Main 3 (corrected ^{14}C-age).

Hatched signature: felling dates of the tree trunk layers left (uncorrected ^{14}C-ages).

Column 2

Spotted signature: felling dates of the tree trunk layers Danube 4 and 5 (dendrochronologically dated), Danube 3/10 (corrected ^{14}C-age).

White signature: felling dates of the Danubian synchronous tree trunk layers left (uncorrected ^{14}C-ages).

Column 3

Felling dates of wood of pile constructions on the Main.

Column 4

Gravel bodies on the Main.

Fl=flood-loam sedimentation.
a =^{14}C-ages concerning the gravels.

Column 5

A =A_h-horizon; b=^{14}C-ages concerning the A_h-horizon. Soil development.

B =B_v-horizon; ( )=weakly developed.
B_t=B-horizon with clay illuviation; ( )=initial type.
S =Pseudogley.
M=Alluvial soil.

Column 6

Horizontal lines: periods of dominating fluvial activity. Vertical lines: periods without remarkable fluvial activity.

that at the next flood the trees are not borne away but are instead covered by sediment. In the fossil exposures one also often can observe that several trees are wedged together. In this form presumably they accelerated the deposition of gravel.

If washed-out *Rannen* drift with the stream, these trunks which weigh up to 20 tons can present a serious danger for shipping traffic as they glide below the water (Neweklowsky 1964). Should they then be deposited on river bars, they gradually decay due to splitting during drying out or to frost splitting in the winter. As the smooth subfossil trunks then lack the anchoring capability of newly uprooted trees they can easily be further transported again. A simultaneous deposition of eroded *Rannen* and freshly washed out trees from sites close to the river bank could therefore have led to a mutual bedding-in – in exceptional cases only in a newly created Holocene gravel body.

The mainly excellent state of preservation of the *Rannen* (Becker 1972) permits the drawing of some conclusions from the conditions of accumulation prevailing at the time: Firstly the washed-out trees could hardly be transported over great river distances, as otherwise the well preserved roots and branches would have been quickly knocked off by scrubbing on gravel. Therefore, the trees carried off by the stream must have been quickly covered with gravel and sand. In addition, both drying-out fissures as well as indications of attack by wood-destroying insects or fungi, are absent. They should have occurred during years or decades of lying upon gravel banks. The dendrochronologically dated year of death of the subfossil trunks should therefore be directly equated to the time of their washing out and deposition.

Larger *Rannen* layers do not represent a single event of fluvial activity. In most cases they are the results of the course of several hundred years of deposition (see Becker 1976). Evidence for it can be given by Fig. 3, which demonstrates the growth and death sequence of the Iron-Roman Age *Rannen* horizon.

Spatiotemporal genesis of a Holocene gravel body as illustrated by the Iron-Roman Age gravel and Rannen *in the Trieb exposure*

The spatial course of washing off the riverine forest and reworking of gravel are more precisely described by way of an analysis of the growth-ages. This is represented in Fig. 15 for the Iron-Roman Age *Rannen* horizon of the Main valley. Between 200–50 B.C. only relatively young, that is 130–240 year-old oaks, fell into the river. In the next period, however, up to 400 year-old trees were eroded. They must have been grown continuously in an undisturbed position in the plain, beyond the period in which those oak sites situated close to the river had already been destroyed. The course of the Iron-Roman Age *Rannen* deposition could be followed in the Trieb exposure from 14 subfossil trunks (see Fig. 16). The tree-ring dated trunks show a trend of increasingly later years of extinction towards the valley edge. From 150 B.C. to 64 A.D. the sedimentation was therefore shifting from the valley centre towards the edge more than 300 m. The inner bedding of the gravel body in which the trunks are buried also shows the sideways shift of the river course and of the sedimentation by means of a gradual falloff to the valley edge. Extensive parts of the some 2.5–3 m thick Holocene gravel body therefore originate in sideways undercutting of the oak-covered outer bank and accretion of redeposited gravel with uprooted trees on the inner bank.

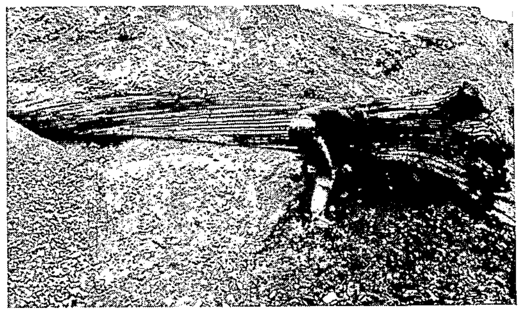

Fig. 14. Oak *Ranne* No. 37 in situ in the gravel pit of Trieb. Position see Fig. 16. Foto: W. Schirmer 12.4.74.

Active and inactive phases of the river during the Holocene

From the preceding description of the course of the *Rannen* and gravel accumulation during the Iron- and Roman Age, one can deduce that such events, even with a varying intensity, took place more or less continually over the Later Holocene. Thus hitherto existing gaps

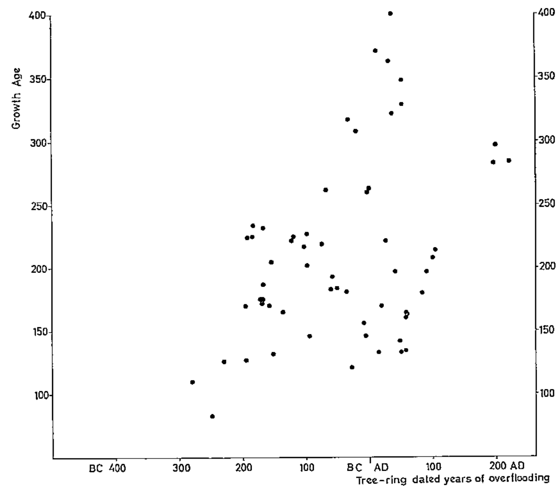

Fig. 15. Growth-age development in the course of the Iron-Roman Age *Rannen* deposition. Each dot shows the reconstructed growth age of one cross-dated trunk at the year of its deposition on the absolute time scale between 400 B.C. to 230 A.D.

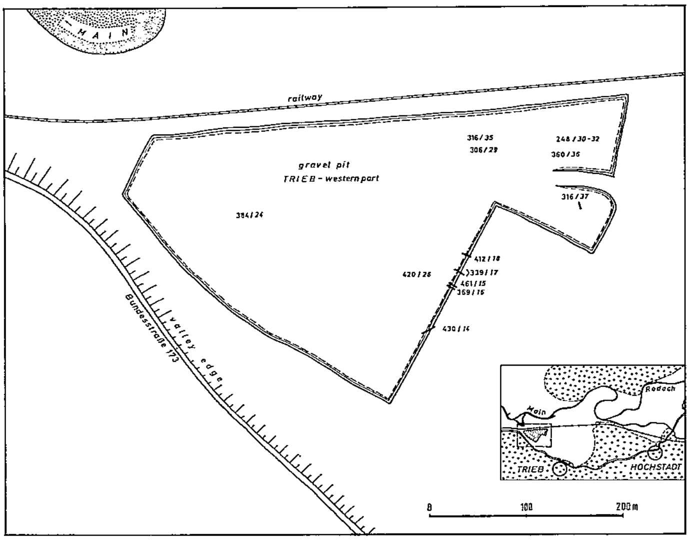

Fig. 16. Spatiotemporal distribution of *Rannen* between 150 B.C.–64 A.D. in the gravel pit of Trieb.
316/37=growth age of an oak trunk/its number.
Cipher with balk=trunk lying in situ.
Cipher without balk=approximate position of the trunk.
The growth age of *Rannen* is generally increasing towards the southwestern valley edge.

can be explained by a still inadequate number of findings. The significant corresponding temporal clustering of dated subfossil trunks on the Main and Danube, on the basis of 1300 evaluated *Rannen*, is obviously evidence against a continuity. Although future finds of trunks from spaces of time not covered with datings may be important for the further progress of the Holocene oak tree-ring chronology, no important change is to be expected in the analyses which would affect the statistical distribution already established.

The information now gathered concerning the history of the Main valley, with periodical alternation of inactive and more active phases, is, moreover, supported by a statistical evaluation of hitherto existing investigations of valleys from the forelands of the Alps to the northern German Plain. A critical survey of the available literature and a series of additional findings not treated here have been made by Schirmer (1973, 1974) and by Becker (1972). Herein it is clearly shown that the gaps between the phases of increased gravel deposition fall in the same Holocene spaces in which hitherto hardly any dendrochronological proof could be found.

Palaeoecology of the Main flood plain during the Holocene

River activity and riverine forest development

The spatiotemporal course of the *Rannen* deposition shows to what extent the development of the riverine forests had been influenced by the changing river activity. In addition, all the preserved subfossil forest remains are characterized by growth-ring numbers which are significantly below the highest attainable ages our oaks in Europe can reach. A collation of the 967 best preserved *Rannen* of the Danube and the Main revealed that 91% of the individuals lie within the 100–300 year-old age group. Only 8% attained the higher age of a maximum of 420 years. In contrast to the above, Huber & Giertz-Siebenlist (1969), for example, found specimens in recent oak forests in the Spessart that reached 600 years and were felled as healthy trees. Quite clearly, the forests in the Holocene river valleys, the remains of which we are investigating today, could not develop undisturbed anywhere over a longer period. To this one must add that after the destruction of valley plain forests decades, possibly centuries, went by until newly accumulated valley areas could be restocked by the oak. Also in the case of the certainly frequent undercutting of higher situated places where the riverine forests mainly escaped annual overflooding, not any trees attaining a really old growth-age have been accumulated. Besides one must consider that at least one catastrophic high-water every thousand years which flooded higher-lying terrace areas led, after months of high-water or floods with drifting ice-blocks during melting in springtime, to the extinction of the forests so that the natural age structure of native oak forests has been disturbed over the whole valley.

For the ecological conditions of the Holocene valleys this meant of course that the forests, after periodic destruction, had to regenerate on the new surface of the valley fills. The fertility of these sites was most definitely dependent on the possibility for fine-grained sediment deposition upon the gravel as well as on the stage of soil development.

Flood loam sedimentation

The Late Glacial and the various Holocene gravel bodies are covered by their own flood-plain sediments which follow the gravel deposition. Occasionally the later flood deposits spread over the earlier sediments (see Fig. 7). The preservation of flood-plain sediments of different age varies greatly. Whether they are more or less preserved or were eroded can be judged from the completeness of the soil on the flood-plain sediment.

The flood loam under the Early Holocene Trieb Soil was often found preserved intact, with a thickness of 50–100 cm (average 80 cm). Flood sediments covering the Atlantic and the Subboreal gravels on the other hand, have only been found preserved as remnants up to now. Their position in age and thus their correlation still remain somewhat unclear. The sediments above the Atlantic gravel are preserved up to 40 cm in thickness, those above the Subboreal gravel with an average of 75 cm.

The flood loam above the Iron-Roman Age gravel which is capped by the Hochstadt Soil Horizon attains 70–120 cm, averaging 110 cm in thickness. An average of between 50 and 100 cm of flood sand and loam lies upon the Middle Age gravel body. The total thickness of the Middle Age flood loam spreading out over the entire valley floor, together with the older loams beneath it, reaches an average of 150–200 cm.

In general an increase of the total thickness of flood sediment in the valley floor for the Later Holocene can be registered. It is due to the well known fact of the anthropogenic exposure of the unconsolidated sediments by means of cultivation clearance on the slopes.

Soil development as an ecological factor for the riverine vegetation

In most of the sections of the valley plain, fossil soils are encountered beneath the surface soil. The old, buried flood plain surfaces marked by these soils are often still intact. Sometimes, however, they have to some extent been

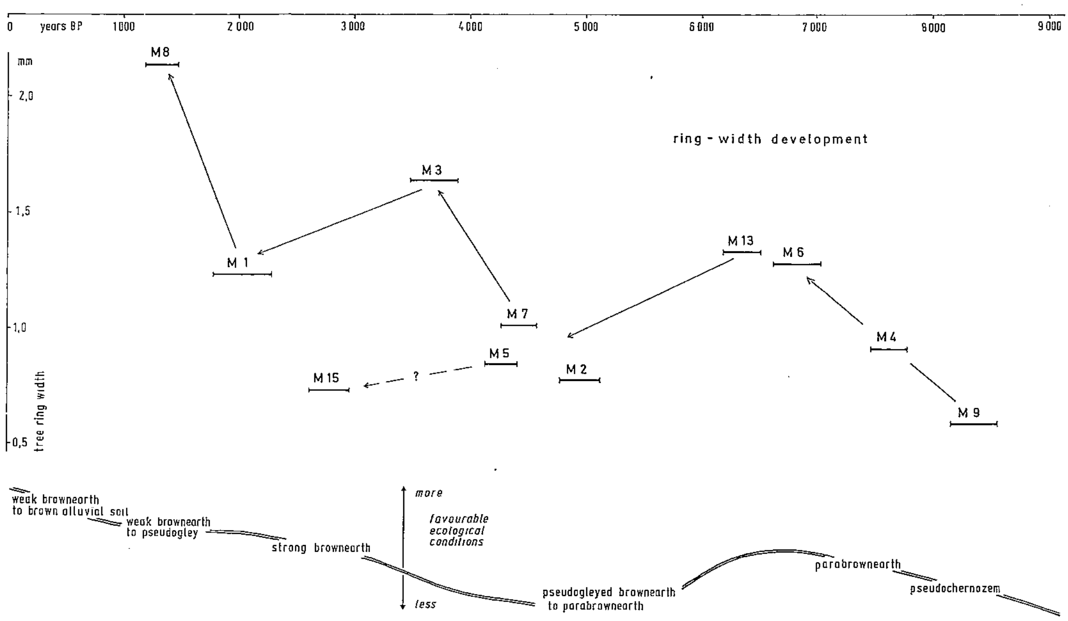

Fig. 17. Ring-width development within the Holocene riverine oak forest of the Main valley. Trend curve of ecological conditions caused by soil development, flood sediments and groundwater.

removed. In most cases, however, the fossil soils allow the tracing back to the type of soil on the buried valley areas (see Schirmer 1977).

The soil of the Early Holocene flood plain (Trieb Soil) is characterized by a relative thick flood-loam substrate and a relative high ground-water table. As examples on other rivers show, in depressions this soil tends to pass into Anmoor and lowmoor bog (Schirmer 1973: 309). With a lowering of the ground-water table during the course of the Early Holocene, braunification of the *Trieb soil* starts. The depth of braunification exceeds up to threefold the thickness of the A_h-horizon (see Fig. 8). Advanced braunification of this soil gave rise to pseudogleying.

A strong brown-earth with the beginnings of clay illuviation has developed upon the Atlantic gravel (Fig. 9). The upper parts of the profile locally is pseudogleyed.

The flood-loam cover on the Subboreal gravel bears a strong brown-earth (Fig. 10). The B-horizon extends into the gravel. The soil is locally pseudogleyed.

The flood-loam cover on the Iron-Roman Age gravel (Fig. 11), which ends with the humic Hochstadt Soil Horizon (A_h), bears a weak brown-earth which extends down just to the top of the gravel, sometimes into its uppermost parts. In this soil the indications of pseudogleying prevail over those of braunification. Thus the soil is less thick and the soil markings are less intense in comparison to the soil above the Subboreal gravel.

Over the Middle Ages gravel in the valley plain, lie flood sand and flood loam, reaching up to the present-day surface. In the upper part of the profile brown soil-sediment is intercalated and superimposed. On this allochthonous soil an autochthonous brown-earth has since developed (Fig. 12). Accordingly, depending on the site within this section of the valley, characteristics of an allochthonous or autochthonous soil are overlapping. The flood sediments described form the present-day valley surface, spreading out over the entire valley floor. On the areas outside the Middle Ages gravel string, a weak brown-earth has developed up to the present. The older soils previously mentioned are buried under it (see Fig. 7). On the Modern Times valley plain, i.e. the high-water bed, which follows the present river as a narrow band, lies a thin, humic allochthonous brown soil.

In Fig. 17, the soil conditions of the Holocene valley-plain, as indicated by their fossil remnants, are arranged as a generalized curve which shows the tendency of these soils to be suitable for the growth of riverine forests: one must consider, however, that the mentioned, now fossil-existing soil type, only signifies the final state of a development which takes place during the indicated time interval. Only in individual cases can the time be confined when the development to the given soil type was achieved as well as the time when the soil development was interrupted by fossilization. These cases are not indicated in Fig. 17.

In the Early Holocene, following the recession of fluvial activity in the ending Late Glacial, the high groundwater table receded. As a result the braunification penetrated deeper into the flood loam cover. At this time, the soil conditions in the valley plain must have achieved a first ecological optimum. The following pseudogleying of these soils must then have been most detrimental to the ecological conditions.

A remarkable improvement in the soil conditions can be assumed, particularly after the increased flood loam deposition which follows the Subboreal gravel deposition. Since that time the soil fertility of the valley plain has increased further, caused by repeated accumulation of flood loams up to the Present Times which also covered the former pseudogleyed sites almost completely.

Therefore it can be assumed that the most unfavourable ecological conditions during the course of the Holocene valley development probably prevailed at the time of the maximum pseudogleying in the valley plain. In as far as it is possible to date this period, it falls within the Later Atlantic and possibly extended into the Subboreal.

Since the early Subatlantic, due to the wide and complete covering of the valley floor with flood loam, the soil fertility has steadily improved towards the conditions prevailing in the valley plain today.

Tree-ring widths of subfossil oaks as indicators of palaeoecological changes in the Main flood plain

The tree-rings in the subfossil remains of preserved Holocene riverine forests give the most accurate indications of the changing ecological conditions in the Holocene Main valley. The tree-ring widths are depending on the quality of the ecological conditions of the site. In Fig. 17, the average ring-widths of all dated *Rannen* are recorded together with their period of growth. As the ring-widths also depend on tree-age (near the centre core wider growth layers are built than in the outer trunk zone), in each case only the average widths of the 150 innermost rings were used from the cross-sections.

The development of the growth-capacity within the Holocene valley plain can be subdivided into three stages: The oldest preserved trunk layers from the Boreal (M9 8520–8120 B.P.) with an average width of 1.57 mm is recognized as extremely narrow. Up to the Early Atlantic the ring widths show a steadily increasing trend. Between 7000–6000 B.P. they achieve some 2.3 mm, thus revealing most favourable ecological conditions. In contrast to this the annual growth-rates in the late Atlantic and early Subboreal (between 5000–4000 B.P.) diminished considerably. A remnant of this locality type was possibly preserved up to the beginning of the second millennium B.C. (Chronology M15). Within the *Rannen* which grew during the Bronze Age a significant increase in tree-ring widths took place. Their growth-capacity of 2.63 mm exceeded by some 40% that of the forests from between 5000–4000 B.P. During the Iron-Roman Age the values drop to 2.23 mm but still lie well above those of the older forests, whereas the oaks of the Early Middle Ages with an average of 3.13 mm indicate a second great improvement of the ecological conditions: These riverine forest remains have ring-widths which are a further 10% above those of the Bronze Age valley plains and 63% above those of the period 5000–4000 B.P. The distinct separation of the ring-widths during the Subboreal also occurs in the subfossil forests of the Danube valley (Becker 1976).

Palaeoecological interpretation of the results

The sedimentological, hydrological, and pedological changes of the Holocene valley localities of the Main were not without effect on the ecological conditions for the riverine forests that developed there. In the form of a trend curve, Fig. 17 represents an attempt to interpret all results in their assumed ecological connection to the vegetation. Neither the accuracy of dating nor the statistical guarantee provided by the collected findings are sufficient to describe in the form of an unbroken chain of evidence the factors which influenced the ecosystem of the Holocene valley plain in various ways. On the other hand the material available is now so large that the main features at least can be considered as reliable. Nevertheless we want to stress that possible influences of Holocene climatic factors, for which there are no indications in our records, have not been taken into account in the following consideration.

The soil conditions in the Early Holocene, given by a flood loam of 0.5–1 m thickness with high level of groundwater in the beginning phase, indicate unfavourable ecological conditions. The later sinking of the groundwater table with subsequent deep-reaching weathering, however, caused an improvement of the sites. Therefore, the trend of tree-rings of the oak forests to increase from the Boreal to the Early Atlantic possibly coincided with the soil development. The obvious reduction in growth-capacity, which was clearly marked in the oaks of the Late Atlantic and the Early Subboreal, took place in the same period in which the soil conditions significantly worsened due to stagnant wetness. The flooding after the Subboreal gravel-redepositing covered extensive valley areas with fresh, fine material. The rapid improvement of the ecological conditions, as evidenced for the first time by the Bronze Age tree-ring patterns, can be closely correlated with the flood loam deposits at least since the Iron-Roman Age. The particularly narrow tree-ring patterns of the *Rannen* M15, which show an undisturbed growth over a long period, can possibly be an indication that locally higher situated stocks, for example on gravel ridges, were also eroded. With progressive flood sedimentation, the wide tree-ring patterns of riverine oaks of the Early Middle Ages characterize the increasing fertility of the valley plain that is typical of the recent Main valley.

Prehistoric land clearance and Late Holocene valley development

If one observes the extent of the Holocene riverine forest destructions, trunk- and gravel accumulations, high floodlevels, the development of the flood-loam deposition, and the soil formation, the Subboreal is in all cases the most drastic period of change in river history. The rapid increase in the growth capacity in the riverine forests of the Bronze Age, as a result of newly deposited gravel and flood-loam sedimentation, is also hardly questionable, because a significant climatic improvement from the Atlantic to the Subboreal Period, as the only other possibility, can be disregarded. Neither can the increase in fine-grained sediment supply be traced back to a loosening of the vegetation cover as a consequence of a drastic climatic recession. The origin of the thick late Holocene flood loam covering can only be explained by human land-clearing activity (Bibliography: see Schirmer 1974). As evidence of prehistoric settlements (for the Upper Rhine–Danube–Neckar region, see Sangmeister 1974) maps of archeological finds show that since the Neolithic Age the river plains and their drainage basins were always specially favoured settlement areas. Studies on slopes have given an insight into the extent to which fine-material redeposition, caused by land clearance since the Neolithic Age has taken place (see Lüning, Schirmer & Joachim 1971). The extent of the connection between human activity and gravel redeposition since the Subboreal must remain unsettled. With the lack of *Rannen* in the Holocene gravel the land clearance in the valleys must have been largely completed. The last larger *Rannen* collections originate from the Early Middle Ages (chronology Main 8). From this time on, intensive land clearance in the flood plain can be reckoned with. Missing subfossil oak trunks in Middle Age gravel bodies as well as pile constructions dating from the beginning of the 13th century A.D. up to the 16th century prove that the flood plain had been completely brought into cultivation.

REFERENCES

Becker, B. 1972: Möglichkeiten für den Aufbau einer absoluten Jahrringchronologie des Postglazials anhand subfossiler Eichen aus Donauschottern. *Ber. Deutsch. Bot. Ges. 85*, 29–45.

Becker, B. 1973: Chronologie des Holozäns mit Hilfe der Dendrochronologie. *Jb. 1973 Akad. Wiss. u. Lit. Mainz*, 180–182.

Becker, B. 1976: Paläökologische Befunde zur Geschichte postglazialer Flußauen im südlichen Mitteleuropa. *Berichte über das Symp. 'Die Dendrochro-*

nologie des Postglazials, Grundlagen und Ergebnisse'. Mainz 1974, in press.

Becker, B., Delorme, A. & Schmidt, B. 1977: Koordination der Jahrringforschung beim Aufbau einer postglazialen Eichenchronologie. *Berichte über das Symp. 'Die Dendrochronologie des Postglazials, Grundlagen und Ergebnisse'*. Mainz 1974, in press.

Graul, H. & Groschopf, P. 1952: Geologische und morphologische Betrachtungen zum Iller-Schwemmkegel bei Ulm. *Ber. d. Naturforsch. Ges. Augsbürg 5*, 3–27. Augsburg.

Hoffmann, D. 1970: *Erläuterungen zur Geologischen Karte von Bayern 1 : 25 000, Blatt Nr. 5831 Seßlach.* 106 pp. München.

Hollstein, E. 1967: Jarringchronologien aus vorrömischer und römischer Zeit. *Germania 45*, 60–84.

Huber, B., Holdheide, W. & Raak, S. 1941: Zur Frage der Unterscheidbarkeit des Holzes von Stiel- und Traubeneiche. *Holz 4*, 373–380.

Huber, B. & Giertz-Siebenlist, V. 1969: Unsere tausendjährige Eichenjahrringchronologie durchschnittlich 57 (10–150)-fach belegt. *Sitzungsber. Österr. Akad. Wiss., Math.-naturw. Kl., Abt. 1, 178*, 37–42.

Jakob, H. 1956: Zur Datierung des 'Rannenhorizontes' und der sog. 'Pfahlbauten' im Main-Regnitz-Gebiet um Bamberg. *Ber. Naturforsch. Ges. Bamberg 35*, 63–82. Bamberg.

Janetzko, P. & Roloff, A. 1970: *Erläuterungen zur Geologischen Karte von Bayern 1 : 25 000, Blatt Nr. 5931 Ebensfeld.* 83 pp. München.

Körber, H. 1962: Die Entwicklung des Maintals. *Würzburger Geogr. Arb. 10.* 170 pp. Würzburg.

Koschel, R. 1970: *Erläuterungen zur Geologischen Karte von Bayern 1 : 25 000, Blatt Nr. 6031 Bamberg Nord.* 167 pp. München.

Lang, M. 1970: *Erläuterungen zur Geologischen Karte von Bayern 1 : 25 000, Blatt Nr. 6131 Bamberg Süd.* 150 pp. München.

Lüning, J., Schirmer, W. & Joachim, H.-E. 1971: Eine Stratigraphie mit Funden der Bischheimer Gruppe, der Michelsberger Kultur und der Urnenfelderkultur in Kärlich, Kr. Koblenz. *Praehist. Z. 46*, 37–101. Berlin, New York.

Neweklowski, E. 1964: Die Schiffahrt und Flößerei im Raume der oberen Donau. *Schriftenreihe Inst. Landeskde. Oberösterreich 16.* 658 pp. Linz.

Sangmeister, E. 1974: Das Land Baden-Württemberg, Bd. 1 Landesgeschichte, 109–125. Staatliche Archiv-Verw. Baden-Württemberg, Stuttgart.

Schirmer, W. 1973: State of research on the Quaternary of the Federal Republic of Germany C 2. The Holocene of the former Periglacial areas. *Eiszeitalter und Gegenwart 23/24*, 306–320. Öhringen/Württ.

Schirmer, W. 1974: Holzäne Ablagerung in den Flußtälern. *In* Woldstedt, P. & Duphorn, K.: *Norddeutschland und angrenzende Gebiete im Eiszeitalter*, 351–365. Koehler Verlag, Stuttgart.

Schirmer, W. 1977: Holozäne Talgeschichte am Obermain. In press.

Suess, H. E. 1970: Bristlecone pine calibration of the radiocarbon time scale from 5400 B.C. to the present. In *Radiocarbon variations and absolute chronology* (Proceedings of the twelfth Nobel symposium, Uppsala 1969), 303–312. John Wiley, New York.