Acta Palaeobotanica 61(2), 136–147, 2021
https://doi.org/10.35535/acpa-2021-0008

e-ISSN 2082-0259
ISSN 0001-6594

A late Würmian and Holocene pollen profile from Tüttensee, Upper Bavaria, evidence of 15 millennia of vegetation history in the Chiemsee glacier region

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Received 14 July 2021; accepted for publication 2 December 2021

ABSTRACT. A late Würmian and Holocene pollen profile from Tüttensee near Chiemsee, Bavaria, covering 14 millennia of vegetation history, shows the late Würmian reforestation of the area, Holocene woodland development, and later the human impact on the landscape. In the early Holocene a distinct *Ulmus* phase preceded the *Corylus* and *Quercus* expansion. Afterwards, between 6000 and 4000 BCE, *Picea* was most common. The expansion of *Fagus* and *Abies* started at 4000 BCE, together with the decline of *Ulmus*. *Fagus* was more common than *Abies*. From 500 BCE *Abies* started to decline, *Fagus* has also declined from 1000 CE onwards. Before the modern times *Picea*/*Pinus* phase *Quercus* is prevailing. The prehistoric human impact is rather weak. A short reforestation phase at ~ 1 BCE – 1 CE hints at the rather complex migration history in this region with so called Celts, Germanic people and Romans involved. Strong human impact indicated by cereals, *Plantago lanceolata*, other human indicators and deforestation started at 900 CE.

KEYWORDS: Late Würmian, Holocene, vegetation history, human impact, southeastern Bavaria

INTRODUCTION

Compared to adjacent regions in the west and southeast, there are only a few modern palynological studies in southern Bavaria (Fig. 1). Apart from pioneer work by Paul and Ruoff (1927, 1932), Langer (1958, 1959, 1962), Schmeidl (1971, 1972, 1977, 1980), Dieffenbach-Fries (1981), and Hohenstatter (1984), there were investigations in the region of the Inn-Chiemsee glacier (Rausch, 1975; Voigt, 1996; Fig. 1), near Rosenheim (Beug, 1976), at Ammersee (Kleinmann, 1995), in the Ammergebirge (Bludau, 1985), in mires around the Auerberg (Küster, 1988), at Pilsensee (Küster, 1995), in eastern Allgäu (Stojakowits, 2014), near Ingolstadt (Peters, 2011; Peters and Peters 2011), and in mires at the Yew forest of Paterzell near Weilheim (Rösch, 2021). The majority of these studies focused on peat deposits and not on lake sediments. However, lake records are well-suited to register

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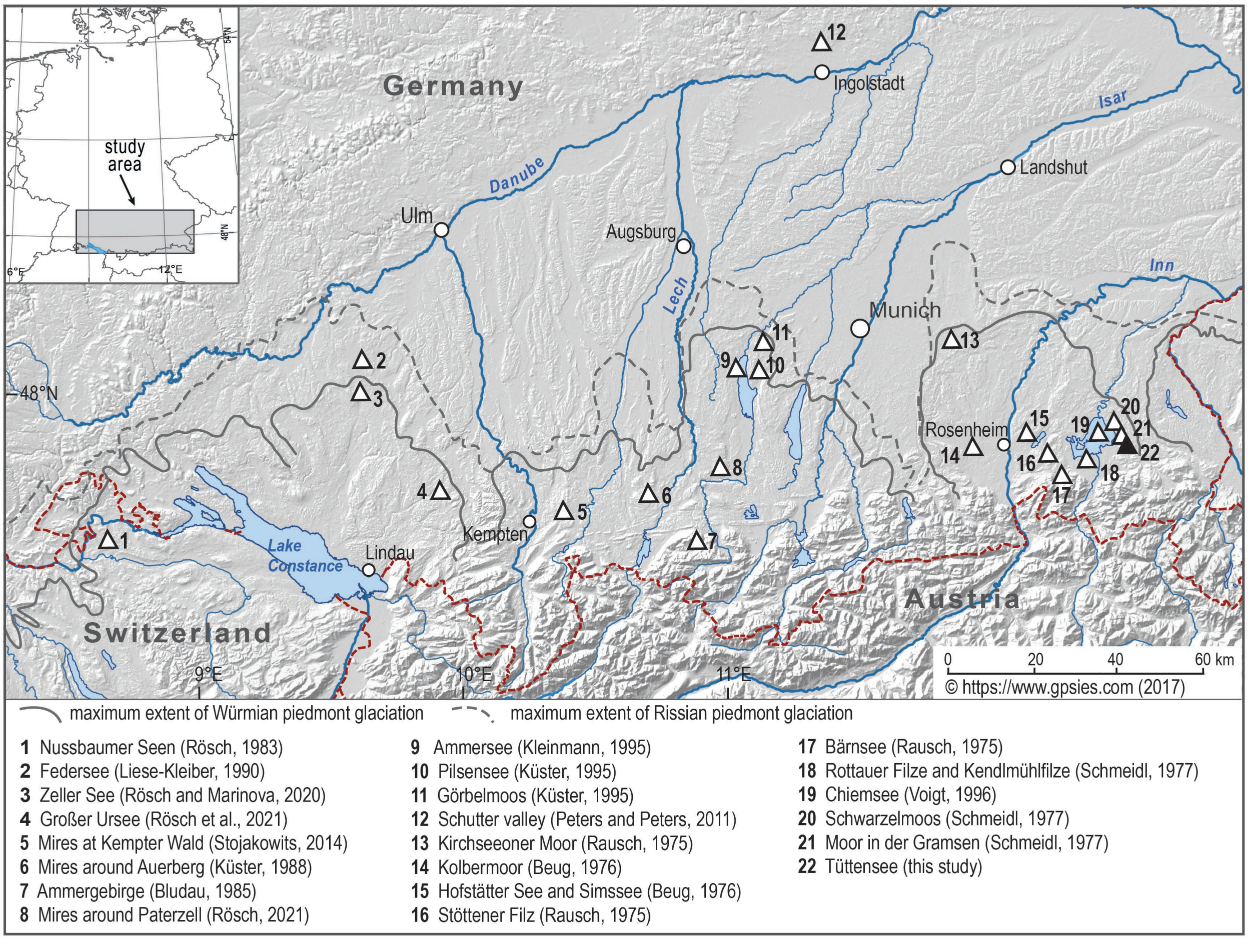

Fig. 1. Study area and situation of the pollen profiles discussed

past changes of vegetation and human impact (Rösch et al., 2021a). Concerning southern Bavaria, only a few lakes have been studied based on pollen analyses so far. Unfortunately, these records lack a robust age chronology and were subsampled at 5 to 10 cm intervals (e.g. Kleinmann, 1995; Voigt, 1996), providing insights into the vegetation history of these areas. Human impact (following Behre, 1981) was also detected in these studies, but due to low sample resolution and lacking age chronology, registered vegetation changes were restricted. Therefore, we analysed a 650 cm long core with subsamples from 2 to 4 cm from a small lake, called Tüttensee, east of Lake Chiemsee. Here we report the palynological results from this high-resolution well-dated record in conjunction with archaeological evidence. Additionally, the hypothesis that Tüttensee originated from a meteorite impact dating ~500 BCE (Ernstson et al., 2010) is also reviewed.

STUDY AREA

Following the Würmian, the retreat of Chiemsee glacier left behind a moraine landscape with many lakes. The Chiemsee is the largest of these lakes, covering an area of 7990 ha. The considerably smaller Tüttensee (10.8 ha) is situated ~4 km south-east of the south-eastern corner of Chiemsee, near the mouth of Tiroler Achen (12°34′E, 47°51′N, 523 m a.s.l.). The kettle hole lake has a maximum length of 420 m, a maximum width of 260 m and a maximum depth of 17 m (Wasserwirtschaftsamt Traunstein, 2021). The lake is surrounded by mires originating from advancing a marginal shallow littoral lake. The lake is eutrophic and belongs to the communities of Grabenstätt and Vachendorf, county of Traunstein in the region Chiemgau, Upper Bavaria. It is surrounded by wetlands and forest on all sides except for the south-east where arable land and predominantly grassland with single farms adjoin. But even the forests are not in a natural state. The village of Grabenstätt is located at a distance of ~2 km to the west and north. The potential natural vegetation would be deciduous forest dominated by *Fagus sylvatica*. The actual vegetation is strongly influenced by agriculture and forestry. The climate is sub-oceanic, with an annual average temperature of ~8°C and an annual precipitation of 1600 mm (Bayerisches Landesamt für Umwelt, 2012).

Recent detailed glacial morphological studies concluded, that Tüttensee did not originate as an impact crater of a meteorite (Huber et al., 2020). Our investigations also contradict clearly the meteorite hypothesis: we found a complete and undisturbed sediment sequence covering the late Würmian and Holocene without any hints of big fires documented by charcoal concentrations in the Iron Age. Tüttensee is a typical kettle hole lake that originated during ice recession towards the end of the last glaciation. Reflecting on initial investigations by Maizels (1992) the morphological Tüttensee depression and surrounding wall should rather be classified as a "rimmed kettle" or "crater kettle" type of glacial melt out kettle hole. See also the comparable work on kettle holes of Götz et al. (2018) in nearby Austria.

MATERIAL AND METHODS

SEDIMENT CORE SAMPLING AND DATING

The studied sediment core was obtained near the northern border of the lake (N 47°50′52.5″; E 12°34′09″ using a Russian peat sampler with a chamber length of 50 cm and a diameter of 5 cm. The complete core had a length of 650 cm. The lithology is given in Table 1. The chronology is based on ten AMS ^{14}C dates measured on terrestrial plant macrofossils (Table 2). The age/depth model was calculated using Oxcal 4.3 (Bronk Ramsey, 2009). Nine of the 10 dates could be used, because one accidentally dated sample was a recent root and gave a false age. Additionally, we constructed a simple visual age model based on interpolation (Fig. 2). The results of the ^{14}C measurements given in Table 2 were calibrated using the IntCal20 calibration curve (Reimer et al., 2020) and the CALIB 8.2 software.

POLLEN ANALYSIS

The core was subsampled for pollen analysis in intervals of 2 to 4 cm resulting in a total of 200 samples. The preparation for pollen analysis was done using ultrasound sieving with a mesh size of 315 µm, partly with HCL, KOH, and SPT treatment after adding *Lycopodium* spore pellets. Each sample was analysed to a sum of 600 tree pollens. The identification and nomenclature of pollen follow Beug (2004), and that of spores Moore and Webb (1978). All charcoals >10 µm were registered. The pollen sum includes all terrestrial pollen except Cyperaceae, aquatics, spores of mosses, and pteridophytes. The pollen zones were defined visually and checked by cluster analysis and broken stick model calculations (Kasim and Raudenbush, 1998), resulting in identical zones. The pollen diagram (Fig. 3) was calculated using the software Tilia 2.1.1 (Grimm, 1984). The description of pollen zones follows Bastin (1979).

RESULTS

The percentages of selected taxa are shown in Figure 3. Twelve local pollen assemblage zones (LPAZs) could be described (Table 3).

At the base, the Bølling/Allerød-Interstadial complex can be identified in pollen zone 1 with a low resolution. *Betula* is dominating, but the

Table 1. Lithology of the Tüttensee profile

Depth (cm below surface)	Material	Other components	Colour	Remarks
0–6	Fully decomposed peat	Roots	Dark brown	Not sampled
7–39	Fen peat, strongly decomposed	Cyperaceae	Dark brown	–
40–53	Lake marl	conchilia	Grey-brown	*Phragmites*, *Carex* fruits
53–196	Fen peat, moderately decomposed	Wood, *Phragmites*	Dark brown	Wood of *Alnus*, *Betula*, *Pinus*
196–213	Lake marl	Conchilia	Ochre-brown	–
213–217	Peaty gyttja	Conchilia, wood	Dark brown	–
217–231	Lake marl with clay	Conchilia, wood	Ochre-grey	Organic layer at 222 cm
231–234	Peaty gyttja	Conchilia, wood	Dark brown	–
234–360	Lake marl	Conchilia	Ochre-grey	260 cm: *Frangula alnus*
361–376	Fine detritus gyttja	Conchilia, wood	Dark brown	362: wood
376–428	Lake marl	Conchilia	Dark grey	With organic mud
428–580	Lake marl	Minerogenic	Grey	Few conchilia
581–625	Lake marl	With silt and clay	Grey	Compact, few conchilia
625–642	Lake marl	With clay	Light grey	Compact, few conchilia
642–>650	Lake marl	With fine sand	Light grey	Compact, very few conchilia

Table 2. Radiocarbon dates

No.	Depth [cm] mean	Lab nr. MAMS-	Age BP	Age BCE/CE 2σ
1	46	44013	517 ± 17	1405–1435 AD
2	70	45758	1969 ± 20	6–86 AD
3	116	45759	3685 ± 24	2143–2016 BC
4	155	44014	4366 ± 22	3026–2910
5	186	47137	5786 ± 21	4709–4580
6	362	44015	8649 ± 27	7728–7592
7	401	45760	(5499 ± 23)	(4369–4325)
8	476	45761	9250 ± 30	8564–8334
9	519	47138	9506 ± 26	8859–8710
10	603	44016	11085 ± 30	11144–10971

percentages of herbs, especially *Artemisia* and grasses, are still high. Weak, but distinct maxima of *Juniperus* and *Hippophaë* are visible.

Subsequently, after the decrease of *Betula* and non-arboreal taxa, *Pinus* dominates the pollen spectrum with values of 60–80% in two millennia, covering the late Allerød and Younger Dryas (pollen zone 2).

In pollen zone 3, the values of *Pinus* slowly decrease and those of *Betula* increase, with two peaks at the beginning and towards the end of this zone. The NAP percentages are low. The curves of first *Ulmus* and later *Corylus* and *Tilia* increase. The curve of *Picea* is continuous and increases slowly. This zone corresponds to the Preboreal.

In pollen zone 4, *Pinus* and *Betula* frequencies decrease further; *Ulmus* and *Tilia* remain on the same level, but *Corylus* and later *Quercus* levels increase. *Corylus* becomes the dominating pollen type with vales of 40–50%. This zone encompasses the Boreal.

At the beginning of pollen zone 5, *Corylus* registers peak distribution, decreases afterwards, but is dominating during the whole zone. *Tilia* reaches its maximum representation and *Fraxinus* increases, as well as *Picea*. *Ulmus*, *Quercus*, and *Picea* are subdominant. The values of *Betula* and *Pinus* decline below 20%. Zone 5 corresponds to the older part of the Atlantic.

In pollen zone 6, *Corylus*, *Quercus*, *Ulmus*, and *Picea* are codominant. *Tilia* still has a proportion of 10%, and *Fraxinus* reaches its highest recorded levels. The NAP sum increases slightly. Among them are anthropogenic indicators like *Plantago lanceolata*, *Rumex*, *Artemisia*, and, towards the end, a single grain of *Triticum*. The zone belongs to the younger part of the Atlantic and dates between 5950 and 3925 BCE.

The rather short pollen zone 7 shows a dominance of *Quercus*. *Ulmus*, *Tilia*, and

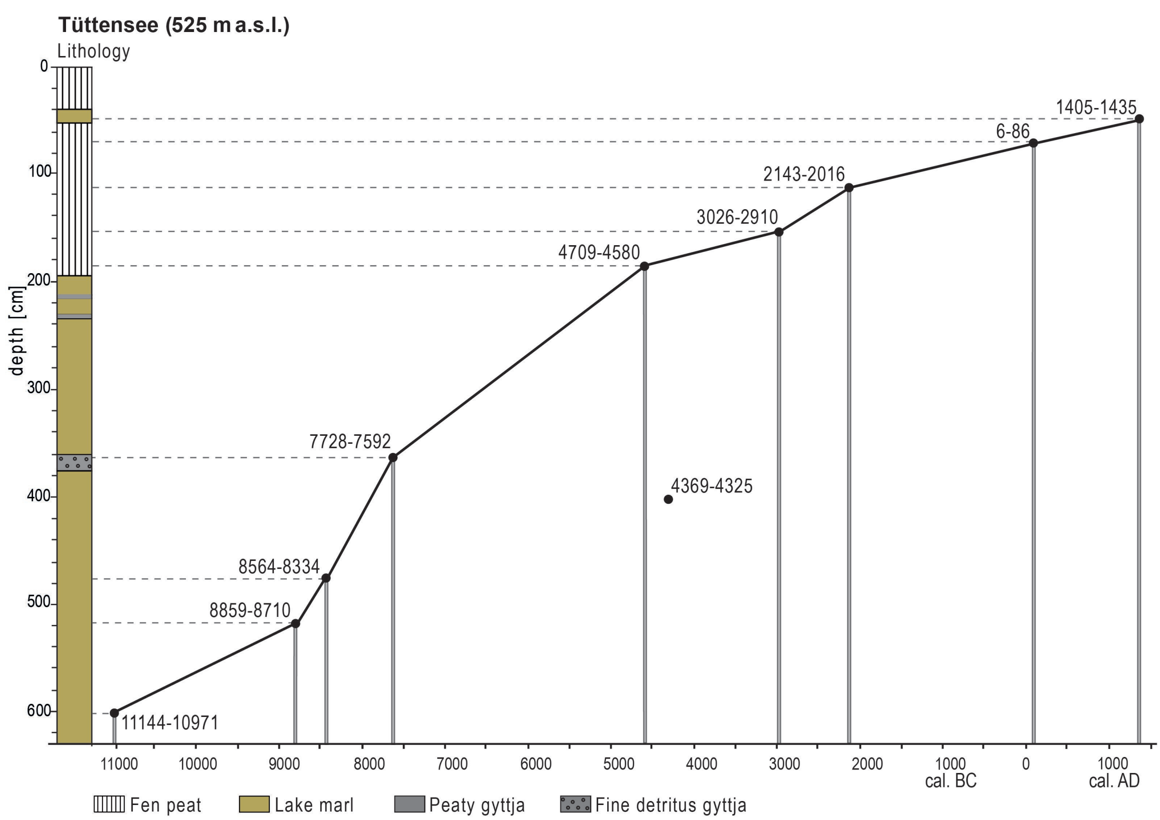

Fig. 2. Lithology and time model of the profile Tüttensee

Table 3. Description of pollen zones

No.	Firbas	Zone name	Event	Upper limit [cm]	Age [BCE/CE]
12	Xb	*Picea-Pinus*	Upper end of core	7	1950
11	Xa	*Fagus-Quercus*	Picea > 15%	27	1730
10	IX	*Fagus*	Quercus > 10%	55.5	940
9	VIII/IX	*Fagus-Abies-Corylus*	Corylus < 10%	78.5	–340
8	VIII	*Fagus-Abies*	Fagus < 35%	122.5	–2235
7	VII	*Quercus*	Abies > 10%	177	–3480
6	VI/VII	*Picea-Corylus-Quercus-Ulmus*	Ulmus < 10%	197	–3925
5	VI	*Corylus-Ulmus-Quercus*	Corylus < 20%	289	–5950
4	V	*Corylus-Pinus-Ulmus*	Pinus < 20%	429	–8133
3	IV	*Pinus-Betula-Ulmus*	Corylus > 20%	509	–9070
2	III	*Pinus*	Ulmus > 1%	562	–10130
1	Ibc/II	*Betula*	Pinus > 30%	640	–11810

Corylus frequencies decrease. *Abies* and *Fagus* appear and start to spread. The NAP sum is unchanged, and human indicators remain low. The zone belongs to the late Atlantic and the beginning of the Subboreal and dates between 3925 and 3480 BCE.

Pollen zone 8 corresponds to the early Subboreal and dates between 3480 and 2235 BCE. *Fagus* is predominant; *Abies* and *Picea* are subdominant. The curve of *Carpinus* is continuous. NAP is more common at the beginning and towards the end. Human indicators are more common; their curves are now sub-continuous.

Pollen zone 9, dating between 2235 and 340 BCE, has decreased *Fagus* values, but slightly increased *Corylus* percentages. Towards the end, there is a weak increase of *Abies percentages*. Except for an increase of *Artemisia*, the NAP and human indicators remain on the same low level. The zone covers the late Subboreal and early Subatlantic.

Pollen zone 10, dating from 340 BCE to 940 CE and, therefore, still belonging to the early Subatlantic, has enduring predominance of *Fagus* and is characterised by a strong decrease of *Abies* representation, recovering slightly towards the end of the zone. *Betula* values are slightly increased. Human indicators remain on the same level.

In pollen zone 11, dating from 940 to 1730 CE (late Subatlantic), NAP and human indicators increase conspicuously. *Fagus* is still dominating, but its curve is slightly decreasing. Here *Quercus is subdominant*. *Abies* is sparsely distributed here, but *Juniperus* and *Corylus* counts increased.

In pollen zone 12, from 1730 to 1950 BCE, the curves of most deciduous trees, as well as NAP decrease suddenly, together with a strong expansion of *Pinus*, *Picea*, and *Betula*.

DISCUSSION

LATE WÜRMIAN, EARLY AND MIDDLE HOLOCENE VEGETATION HISTORY

The profile covers the most of the late Würmian and the Holocene. The origin of the lake as a meteoritic impact crater dating into the Iron Age can therefore be excluded. The late Würmian sequence at the base seems incomplete: Whereas the Oldest Dryas with open steppe to tundra vegetation and therefore dominance of NAP was not covered by the core, the phase of dominant shrubs with *Juniperus* and *Hippophaë* is most probably lacking because of a hiatus. The rest of the late Würmian sequence is typical for elevations below 800 m a.s.l. in southern Germany and surrounding pre-Alpine areas such as Lobsigensee, Nussbaumer Seen, Durchenbergried, Langegger Filz, Kulzer Moos, or Federsee (Lang, 1994). The landscape was covered by rather sparse *Pinus* forest. A decrease of trees during the Younger Dryas is not detectable. A second establishment of *Betula* during the Preboreal is a widespread phenomenon along the northern fringes of the Alps. Afterwards, the history is different from regions further to the west: there is an expansion of *Ulmus* and later *Tilia* before the main spread of *Corylus*. The *Ulmus* curve exceeds 10% already before 10000 BCE, the *Tilia* curve 5% before 9000 BCE. The mass expansion of *Corylus* starts hardly before 9000 BCE. The maximum values of *Corylus* are recorded with 40%, less than at most sites in the Rhine glacier

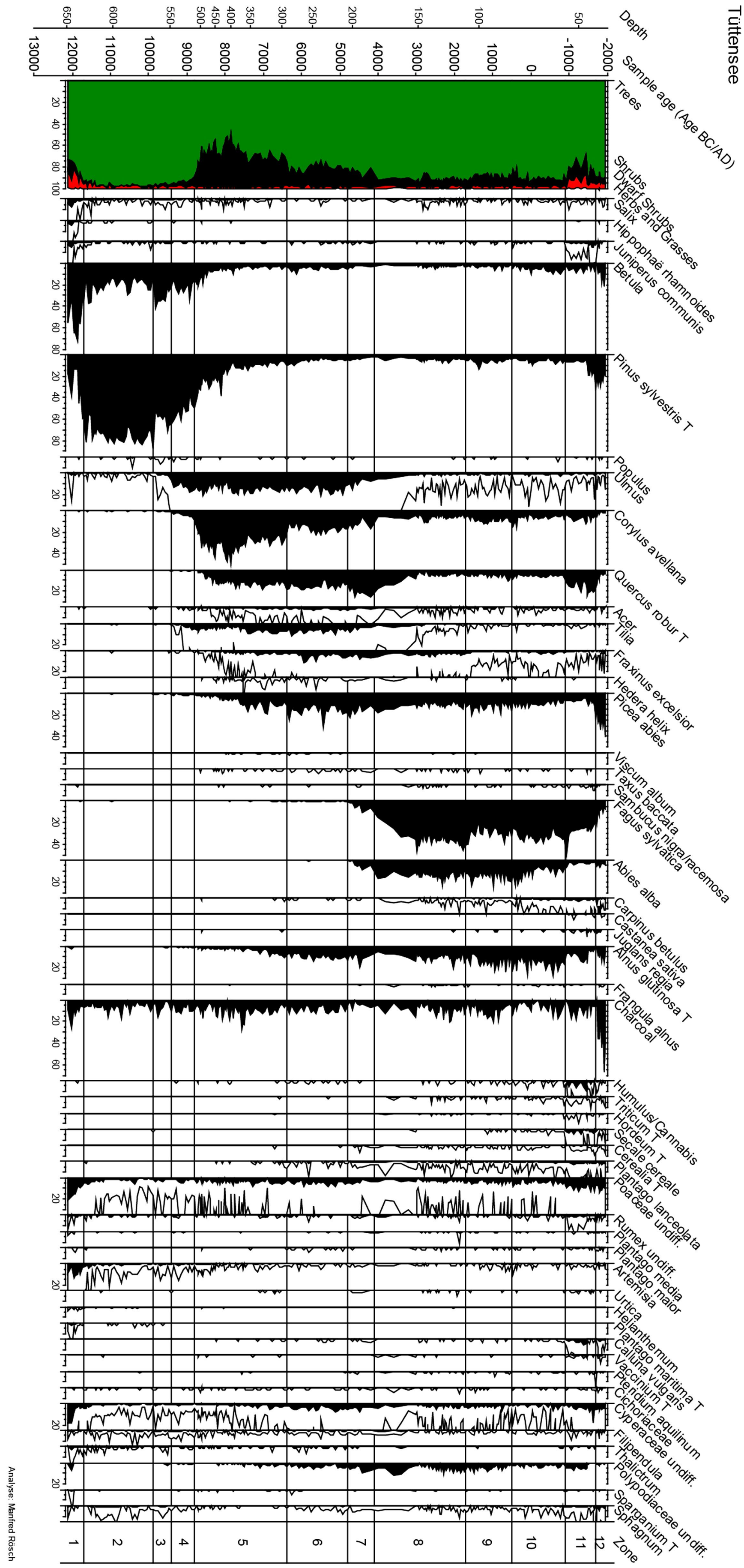

Fig. 3. Tüttensee, Pollen, spores, and micro-charcoals

area. But at Großer Ursee, located between the Rhine and Iller glaciers, *Corylus* remains also below 50% (Rösch et al., 2021b) due to increasing continentality towards the east.

First anthropogenic forest disturbances occur between 6000 and 5000 BCE, most probably caused by Mesolithic or even Early Neolithic groups (Kossack and Schmeidl, 1974/75).

The early expansion and high importance of *Ulmus* is another typical feature of the Würmian glaciated Bavarian Alpine foreland (Küster, 1990, 1995). The *Ulmus* decline starts shortly before 4000 BCE, synchronously to many other regions of the Alpine foreland, and is a rather long-lasting process, terminating at ~3000 BCE. The recession of *Tilia* and *Fraxinus* starts somewhat later, after 4000 BCE, coinciding with the spread of *Fagus* and *Abies*. At the same time, *Picea* values decline, and *Quercus* reaches maximum distribution between 4200 and 3500 BCE. Apart from a continuous curve of *Plantago lanceolata*, human indicators remain weak. There is also, in contrast to the Rhine glacier region, no increase of *Corylus* levels and charred particles, which would indicate Late Neolithic slash-and-burn agriculture. Between 4000 and 3000 BCE, corresponding to the Younger, Late and Final Neolithic, during the 1st phase of *Quercus* dominance, when *Fagus* and *Abies* expanded, there is again woodland disturbance, now with clear evidence of human impact.

HUMAN IMPACT AND THE ANTHROPOCENE

A *Quercus* expansion and the decline of *Picea*, *Ulmus*, and *Tilia* frequencies are difficult to explain as natural woodland development or by a climatic change. Therefore, we would like to stress some kind of human impact, which is to be expected during the Younger and Late Neolithic, as visible in many pollen profiles of the northern pre-Alpine lowlands, for example Pilsensee (Küster, 1995), around Auerberg (Küster, 1988), Federsee (Liese-Kleiber, 1990, 2016), in Upper Svabia and at Lake Constance (Rösch et al., 2021). Promotion of *Quercus* is typical for the Bronze Age, the Iron Age and medieval woodland management known as "Mittelwaldwirtschaft", a forest management system working with two tree layers, an upper layer consisting of old oaks and a lower layer cut down every three decades (Bärnthol, 2003). But this kind of forest management is not proved for the Neolithic. From a woodland management preferring *Quercus,* wood pasture with pigs would benefit. Therefore, it would be interesting if studies of Neolithic animal bones would support this idea.

Between 3000 BCE and 1000 CE, the landscape remained densely forested, with *Fagus* as the dominant taxon, accompanied by *Picea*, and *Abies*, the latter getting rarer from 300 BCE onwards. The rather weak human impact in the Bronze Age and the Iron Age and deforestation are perhaps caused by the situation of the profile in the always forested fringes of the lake where upland pollen was filtered out to a high degree (Fyfe et al., 2013).

Carpinus is never abundantly represented. Some secondary *Corylus* peaks occur, which, together with charcoal peaks, may indicate small-scale shifting cultivation or at least coppice forestry. These peaks date to 3000, 1000 and 500 BCE, corresponding to the Final Neolithic, Late Bronze and Late pre-Roman Iron Age. Similar *Corylus* peaks of the same age are also visible in pollen diagrams at Zeller See in Upper Swabia (Rösch and Marinova, 2021).

Recently Bronze Age and particularly Iron Age interruptions of land use, indicated by reforestation initiated by *Betula* and other pioneers, draw attention (Müller, 1962; Rieckhoff and Rösch, 2019). In the Tüttensee profile there are longer lasting phases with higher *Betula* percentages, indicating coppice forestry, particularly in the 6th and 5th millennia BCE, and from 500 BCE onwards, but only a few weak and short *Betula* peaks occur, perhaps indicating abandoned fields, at ~900, 720, 270, 135–90 BCE and 1 CE, and a last one at 610 CE. Primarily they indicate local events like the abandonment of nearby fields or villages.

Of particular interest are the *Betula* peaks of the Late Iron Age due to their (pre)historical background: at ~100 BCE the Celtic population of Southern Germany started to leave their fortified urban settlements (*oppida*), open villages and rural estates (Rieckhoff, 2007). However, the land did not remain abandoned for long as it was occupied by different Germanic people. In Bavaria we could identify the South-Eastern Bavarian group (SOB group), which came from Thuringia (Rieckhoff, 1993, 1995). This SOB group no longer encountered the Celts but used their abandoned land, often at the same places as their forerunners whose former fields were still recognisable on the basis of a pioneer woodland with a lot of

Betula. Finally, the SOB group disappeared, as well, not later than 40 BCE. A Celtic land abandonment is likewise visible in all pollen profiles in south-west Germany, however the immigrants are not known so well as in Bavaria (Rieckhoff and Rösch, 2019).

If those profiles are compared with Tüttensee in the Chiemgau, it is doubtful whether history followed the same course here. Chiemgau is the name of the region around the Chiemsee between the rivers Inn and Salzach. In Roman times the Inn marked the border between the province of *Raetia* on the left and the province of *Noricum* on the right side of the river. This may perhaps explain why the local (Celtic?) population (*Alauni?*) of the Chiemgau stayed longer than the Celts west of the Inn, and why the SOB group, immigrating in the 1st third of the 1st century BCE, either settled alongside them or even partly mixed with them. Whatever kind of coexistence of the two different ethnic people we should imagine, in the end all inhabitants left the Chiemgau at any rate not later than 40 BCE. According to the archaeological record, if we follow the revisited new chronology (Rieckhoff, 1995; Rieckhoff and Rösch, 2019) of the scarce single and settlement finds (Zanier, 2004: 239), this was the end of permanent settlement in the region until the Romans came. As in *Raetia* as well, effective emigration occurred in this time period which probably caused an interruption of land use as indicated by the *Betula* peak (20 BCE – 20 CE). Consequently, when the Romans arrived, they probably met a dense forest dominated by *Fagus*.

The most important Celtic settlement in the Chiemgau was Stöffling, Lkr. Traunstein, ~10 km north of Tüttensee, unequivocally dated from the 3rd to the middle of the 1st century BCE (Irlinger, 1990). Its successor was the nearby *vicus Bedaium*-Seebruck at the north shore of the Chiemsee, also the earliest Roman foundation in the Chiemgau at~50 CE (Keller, 1981). Some objects, pottery and brooches, point to a Celtic forerunner of Roman Seebruck, existing at the same time as Stöffling, i.e. until 40 BCE at most (Irlinger, 2004). In view of the undisputed hiatus until the Roman occupation, some construction timber (*Quercus*) finds from the long-term excavations at Seebruck, dated by dendrochronology rather precisely between 6 BCE and 8 CE, were quite unexpected (Burmeister, 1998). Such an early Roman guard after the conquest at 15 BCE can be explained by the location of Seebruck at the main traffic route along the Alps from west (Bregenz, Lake Constance) to east (Salzburg). Unfortunately, there is no relationship between the timber and any archaeological object therefore we have only this date but nothing more. Consequently, the constructor of this presumed rack is still doubtful. However, it is not necessary to assume an isolated military post stimulating the land use which must have totally declined before, when the Celtic and Germanic groups had left. Thus, even a Roman rack would not contradict the *Betula* peak (20 BCE – 20 CE).

Medieval deforestation started rather late, in the 10th century CE, and is, compared to other profiles, rather weak with NAP values below 15%, which again could be explained by the filter effect of the lakeshore vegetation. Partial clearing of the wetland forest is indicated by a decline of *Alnus* and an increase of Cyperaceae and Poaceae, the latter indicating, together with an increase of *Juniperus*, intense forest pasturing.

LAKE LEVEL FLUCTUATIONS AND CLIMATE

Several lake level fluctuations are recorded in the Tüttensee profile (Table 1). Evidence for low water levels includes the deposition of peat or shallow water sediments above lake marl. From a certain point onwards, after ~4000 BCE, silting-up developed so far, that peat accumulation became the normal process. Deep water levels could have been no longer recorded, but very high water levels, when again lake marl formation instead of peat accumulation took place. This was the case at a profile depth between 53 and 40 cm, corresponding to 1090 to 1567 CE, covering the most parts of the Little Ice Age and some time before. Lower water levels developed at ~7760–7650 BCE, 4750–4670 BCE and 4360-4280 BCE. The first two lower lake levels covering the late Atlantic period were also detected at Nussbaumer Seen (Rösch, 1983), at Federsee (Liese-Kleiber, 1990), and at Ammersee (Kleinmann, 1995). At Federsee and Ammersee other lower water stands were recorded during the Subboreal, whereas at Tüttensee a long-lasting rather low water level existed throughout almost the entire Subboreal period up to the Middle Ages. Only in the medieval period and the Modern Age, between 1090 and ~1560 CE the lake level record shows a last strong rise with precipitation of lake marl. Lake level fluctuations could be caused by climatic change (Liu et al., 2008). The pollen curves show no clear correlation to the lake level. Perhaps the increase of *Alnus* corresponding with a deep level at 7300 BC, and the increase of Cyperaceae corresponding with the high lake level from 1000 AD onwards can be considered exceptions.

THE ORIGIN OF TÜTTENSEE

Ernstson et al. (2010) postulated that the origin of the Tüttensee was caused by a large meteorite impact at ~500 BCE in the Celtic period. From a glaciological point of view, the hollow of Tüttensee is related to dead ice which was cut off from the Inn-Chiemsee glacier during the ice decay after the Last Glacial Maximum (LGM) (e.g. Ganss, 1977; Doppler and Geiss, 2005; Huber et al., 2020). Our results support the glaciological explanation because of the following reasons:

1. The vegetation history documented by sediments and their pollen content started already in late Glacial times at ~12000 BCE.
2. There are no disturbances or any intercalations in the fen peat of our profile which could be assigned to an impact of a meteorite into the lake. Furthermore, no significant charcoal peak was detected ~500 BCE, nor local vegetation responded in any unusual way, nor a hiatus occurred.
3. If a meteorite impact during the Iron Age created Tüttensee, all sediments older than Iron Age would be lacking, which is not the case.

Therefore, the meteorite impact hypotheses must be rejected.

SUMMARY AND CONCLUSION

A 6.5 m thick littoral profile of Tüttensee, consisting of lake marl in the lower parts and an alternation of peat and lake marl in the upper part was studied by pollen analysis and dated with 10 radiocarbon dates, nine of which could be included into the time model. The lithological sequence covers chronologically most parts of the late Würmian and the Holocene. The results indicate that the lake is of glacial origin and not created by a meteorite impact during the pre-Roman Iron Age. The Holocene vegetation history shows some differences to regions further to the west or east: *Ulmus* spread earlier than *Corylus*. *Quercus* was the third established thermophilous taxon. The main expansion of *Picea* and *Tilia* started synchronously at 7500 BCE. The rise of *Fagus* and that of *Abies* as forest components were again synchronous, starting after 5000 BCE. This coincides with the *Ulmus* decline and a *Fagus* maximum. *Fagus* was the dominant tree from 3500 BCE to 1700 CE. Afterwards, *Picea* and *Pinus* have been dominating. Apart from a few single earlier grains, human indicator pollens (*Cannabis*/*Humulus*, *Triticum* type, *Hordeum* type, Cerealia undiff., *Plantago lanceolata*, *Rumex*, *Plantago media* and *major*, *Artemisia*, *Urtica*, *Calluna vulgaris*) occur regularly from 4000 BCE onwards, corresponding to the Younger Neolithic, but remained rather sparse during prehistory, getting abundant at 900 CE when also a strong deforestation took place. Low water levels could be detected based on changes of the sediment type during the late Atlantic and early Subboreal. Afterwards, fen peat was accumulated until a steep rise in water level, mostly during the late medieval period, when again lake marl was deposited.

ACKNOWLEDGEMENTS

We thank the owner of Tüttensee, Freiherr von Frede, for the coring permission.

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