sciendo
Austrian Journal of Earth Sciences | Vienna | 2025 | Volume 118 | 61–73 | DOI: 10.17738/ajes.2025.0003

Identification and ^{14}C-dating of Quaternary wood samples dredged from groundwater-filled gravel pits in the UNESCO World Heritage Landscape of Lake Neusiedl (Northern Burgenland, Austria)

Hermann Häusler[1*], Otto Cichocki[1], Eva Wild[2] and Peter Steier[2]

[1)] University of Vienna, Josef Holaubek-Platz 2, A-1090 Vienna, Austria
[2)] Vienna Environmental Research Accelerator (VERA)-Laboratory, Faculty of Physics, Isotope Physics, University of Vienna, Währingerstrasse 17, A-1090 Vienna, Austria
[*)] Corresponding author: hermann.haeusler@univie.ac.at

Keywords: Quaternary, Illmitz Formation, dredged wood, wood vegetation type, radiocarbon dating

Abstract

In the lowlands of eastern Austria, the Quaternary deposits are underlain by Neogene formations of the Danube/Kisalföld Basin that in turn forms the westernmost bay of the Miocene Central Paratethys. The younger Middle Pleistocene to Holocene deposits of the UNESCO World Heritage Landscape of the Nationalpark “Neusiedler See - Seewinkel” are known as the Illmitz Formation. In the Seewinkel Plain, this formation covers an area of 350 km^2 and comprises deposits from a few meters to 20 m thick, which are interpreted as sediments of an anastomosing river system. Youngest fine-grained lacustrine deposits of the Illmitz Formation below salt pans near Podersdorf am See range from ~11 000 calibrated years Before Present (cal BP) to ~8 000 cal BP. Hence also comparable young coarse-clastic channel deposits of the Illmitz Formation were expected. Wood samples dredged from gravel pits in the Seewinkel Plain in the years 1988 and 1996 yielded radiocarbon ages ranging from ~43 600 cal BP to ~32 500 cal BP. In contrast, recently dredged wood remains yielded minimum radiocarbon ages exceeding ~50 000 years. Surprisingly, older deposits of the Seewinkel Plain were dated from both surface of gravel pits and subsurface of salt pans. On the one hand, fine-clastic deposits on top of Seewinkel gravel pits were luminescence dated ~100 to ~55 ka. On the other hand, the deposition of a salt-bearing gravelly silt, the so called “salt-bearing horizon” below salt pans was attributed to MIS 5e (~130 to ~115 ka). Therefore, the wood remains with minimum radiocarbon ages of over 50 000 years probably were deposited in younger channel fills between the salt-bearing horizon and the luminescence dated fine-clastic deposits. Ultimately, it cannot be ruled out that at the base of the Illmitz Formation older wood remains were relocated either from fluvial deposits of paleo-Danube that date back to the Early Pleistocene or from underlying lignite-bearing deposits of Late Neogene. Overall, the multitemporal deposition of woods in climatically changing environments since the beginning of the Rissian glaciation (~MIS 11) may have spanned a period of approximately 400 000 years.

Wood anatomical studies allowed identifying several species, among them climatically indifferent taxa as, e.g., *Larix/Picea* (larch/spruce) and *Pinus* (pine) as well as thermophilous ones such as *Fraxinus* (ash), *Ulmus* (elm) and *Quercus* (oak). Decimeter-sized dark brown coalified wood residues with rounded edges were dredged from the base of gravel pits. The dark color of wood remains indicates either a completely different chemical environment at the base of the Illmitz Formation or more probably a much longer exposure time in fluvial deposits than for the light brown wood samples.

Introduction

In eastern Austria, the area of Lake Neusiedl (German: Neusiedler See, Hungarian: Fertőtó) and of neighbouring Seewinkel extends from northern Burgenland to the Hungarian county of Győr-Moson-Sopron (Fig. 1a). Due to its numerous soda pans and smaller lakes the Seewinkel also is termed Lake District. In the following we instead use the term Seewinkel Plain which merges east into the neighbouring Kisalföld, the Little Hungarian Plain. The Seewinkel Plain borders Lake Neusiedl to the southeast and the Parndorf Plateau to the north. Since 1982 Lake Neusiedl and its Lake District have enjoyed protection through the Ramsar Convention on Wetlands (Fischer, 1993) and since 2001 it has been a cross-border UNESCO World Heritage Site. The region is characterized by low-altitude and low-relief landscape. Over a distance of ~20 km, the approximately 350 km² Seewinkel Plain declines from ~130 m above Adriatic in the northwest to an altitude of ~115 m in the southeast. The height of the lowest measured point in Austria near Apetlon is 114 m above the Adriatic which corresponds to the height of gauge zero of Lake Neusiedl. The Fertő/Lake Neusiedl cultural landscape includes numerous abandoned gravel pits and few are still in mining. For decades, companies in northern Burgenland used gravel for production of concrete. In the Seewinkel Plain, gravel is mined with official approval by dredging from groundwater-filled gravel pits. Since wood remains in the gravel beds have a negative effect on the quality of the concrete, they were and are sorted out by hand and piled up near the extraction facilities (Fig. 2a). Tree trunks were rarely found due to weathering and disintegration into smaller pieces. Only in-situ finds of larger pieces of wood were discovered by divers in a gravel pit filled with groundwater near Wallern

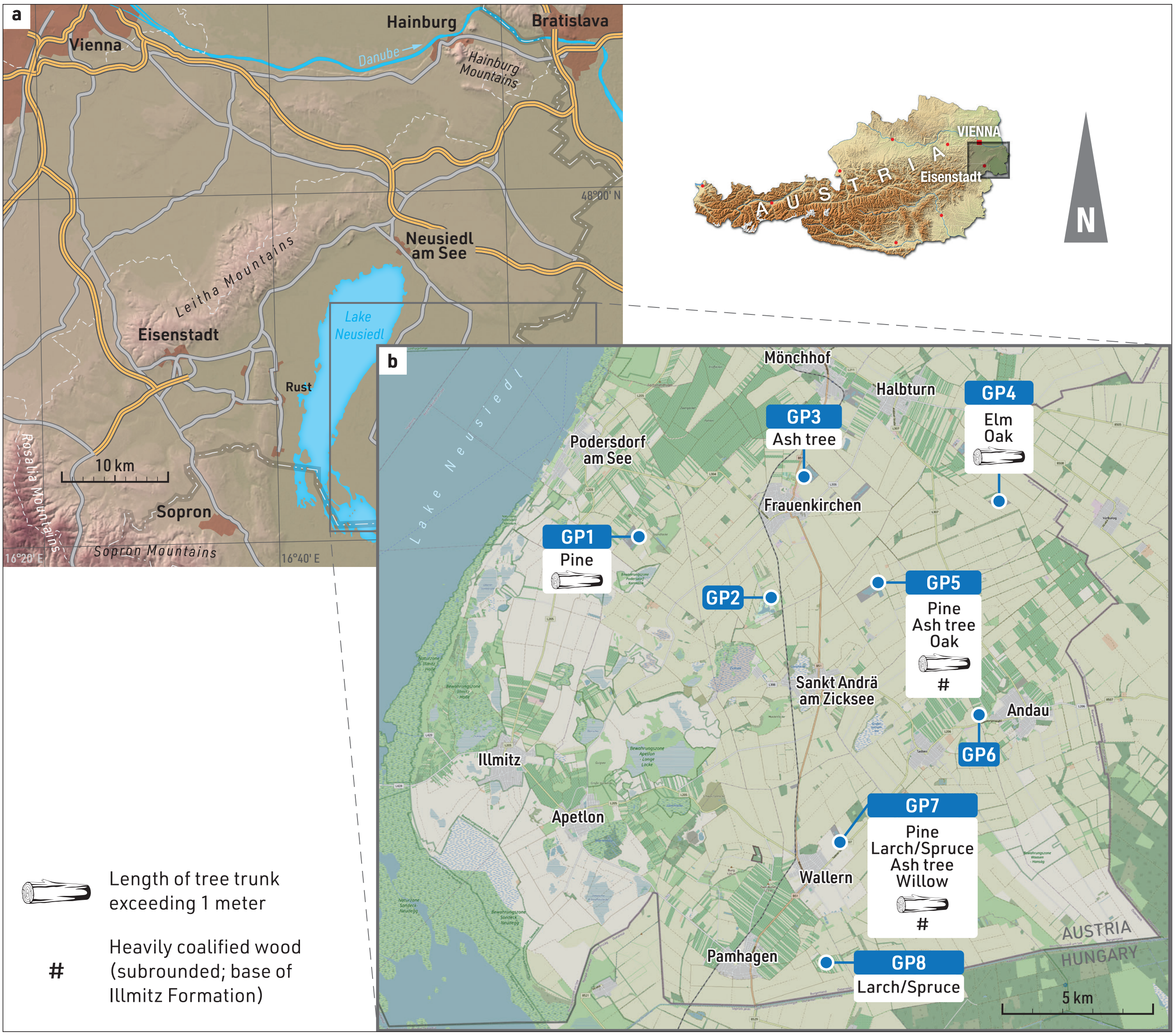

Figure 1: (a) Area of investigation in the Seewinkel Plain, the Lake District east of Lake Neusiedl (OpenStreetMap). **(b)** Sampling locations of groundwater-filled gravel pits 1–8 (GP1-GP8) and determined dredged wood samples (OpenStreetMap).

Location	Gravel Pit	Sample	Lab.-Nr.	δ13C (‰)	14C-age (years BP)	Calibrated age (cal BP)
Gravel pit of Steiner company southeast of Podersdorf am See	**GP1**	1988	VRI-1019 BSTNA	–	**32,600** $^{+2,000}_{-1,600}$	41,800 (95.5%) 34,300
Gravel pit of Steiner company southeast of Podersdorf am See	**GP1**	1988	VRI-1019 BSTNB	–	**27,800** $^{+1,100}_{-900}$	34,500 (95.4%) 30,100
Gravel pit of Steiner company southeast of Podersdorf am See	**GP1**	2011	VERA-5874	−22.5±3.4	**50,100** $^{+2,800}_{-2,100}$	–
Former gravel pit west of Andau	**GP6**	1996	VRI-1832	–	**37,400** $^{+2,100}_{-1,700}$	46,800 (95.4%) 39,000

Table 1: ^{14}C-ages and δ^{13}C-values of wood sampled in gravel pits GP1 and GP6 of the Seewinkel determined by the VRI (Vienna Radium Institute) laboratory in 1988 and 1996, and by VERA (Vienna Environmental Research Accelerator) in 2011. Calibration was performed with OxCal 4.2 (Bronk Ramsey, 2009) and the IntCal20 calibration curve (Reimer et al., 2020). For the VRI samples only rounded ^{14}C-ages with asymmetric uncertainties are documented. Therefore, to allow for a calibration with IntCal20 we back-calculated the F^{14}C-values. For the definition of F^{14}C see Reimer et al. (2004). However, the influence on the uncertainties is negligible. The finite ^{14}C-age of VERA-5874 lies outside the time range of the IntCal20 curve. For location of samples from gravel pits see Figure 1b.

Figure 2: (a) Dredged wood from a gravel pit northeast of Wallern im Burgenland (GP7). Larger pieces of wood usually disintegrate as soon as they are exposed to weathering. The mass accumulation of decimeter sized wood fragments therefore indicates the decay of larger trunks. **(b)** Remains of a tree trunk over a meter long and ~30 cm thick from the gravel pit Göglhof southeast of Halbturn (GP5).

in Burgenland (GP7) at a depth of 10–12 meters (Hodits, 2006).

Before the turn of the millennium only three samples of wood residues have been radiocarbon dated. The previous radiocarbon dating of larger wood remains was arranged by former State geologist of Burgenland Franz Sauerzopf (GP1 southeast of Podersdorf am See, sample “1988”, VRI-1019 (Fig. 1b) and by Franz Klein (GP1 southeast of Podersdorf am See, sample “2011”, VERA-5874). The latter trunk was identified as pine by Georg Grabherr (University of Vienna) and dated to ~50 000 BP. It was exhibited for many years in the Information Center of the Lake Neusiedl - Seewinkel National Park in Illmitz (Anonymus, 2015). Another sample of wood from a former gravel pit west of Andau (GP6, sample “1996”; VRI-1832) was dated to ~37 000 BP respectively ~45 000 cal BP (Table 1). The relatively younger radiocarbon age of wood residues from GP1 southeast of Podersdorf am See (sample “1988”) of VRI-1019 BSTNA yielding ~32 000 BP respectively ~40 000 cal BP and of VRI-1019 BSTNB yielding ~28 000 BP respectively ~34 000 cal BP was motivation for the systematic collection and radiocarbon dating of wood residues from abandoned and still operating gravel pits. In the final analysis we expected an improved stratigraphic classification of the Quaternary deposits of the National Park Neusiedler See-Seewinkel.

2. Geological settings of the “Nationalpark Neusiedler See – Seewinkel”

The lowlands of the “Nationalpark Neusiedler See - Seewinkel” are underlain by Neogene formations of the Danube/Kisalföld Basin that in turn forms the westernmost bay of the Miocene Central Paratethys (Harzhauser et al., 2024). The Paratethys in Paleo-Europe was a large epicontinental sea that came into existence around the Eocene/Oligocene boundary due to the emerging mountain ranges, which divided the former Tethys Ocean during the Alpine orogeny (Harzhauser et al., 2024). When from Pannonian to Pontian, a time span from ~11.6 Ma to 5.3 Ma (Harzhauser and Piller, 2005) the marine Pannonian Basin of the Central Paratethys was transformed into brackish Lake Pannon, the lake gradually became filled by fluvial deltas (Harzhauser et al., 2024; Magyar et al., 2013). In the Seewinkel, these several hundreds of meters thick deposits of Lake Pannon consist of an intercalation of tens of meters of thick sand with tens of meters of thick marl, the latter rich in lignite. This Late Pannonian stack of lacustrine and fluvial deposits of the Seewinkel Plain

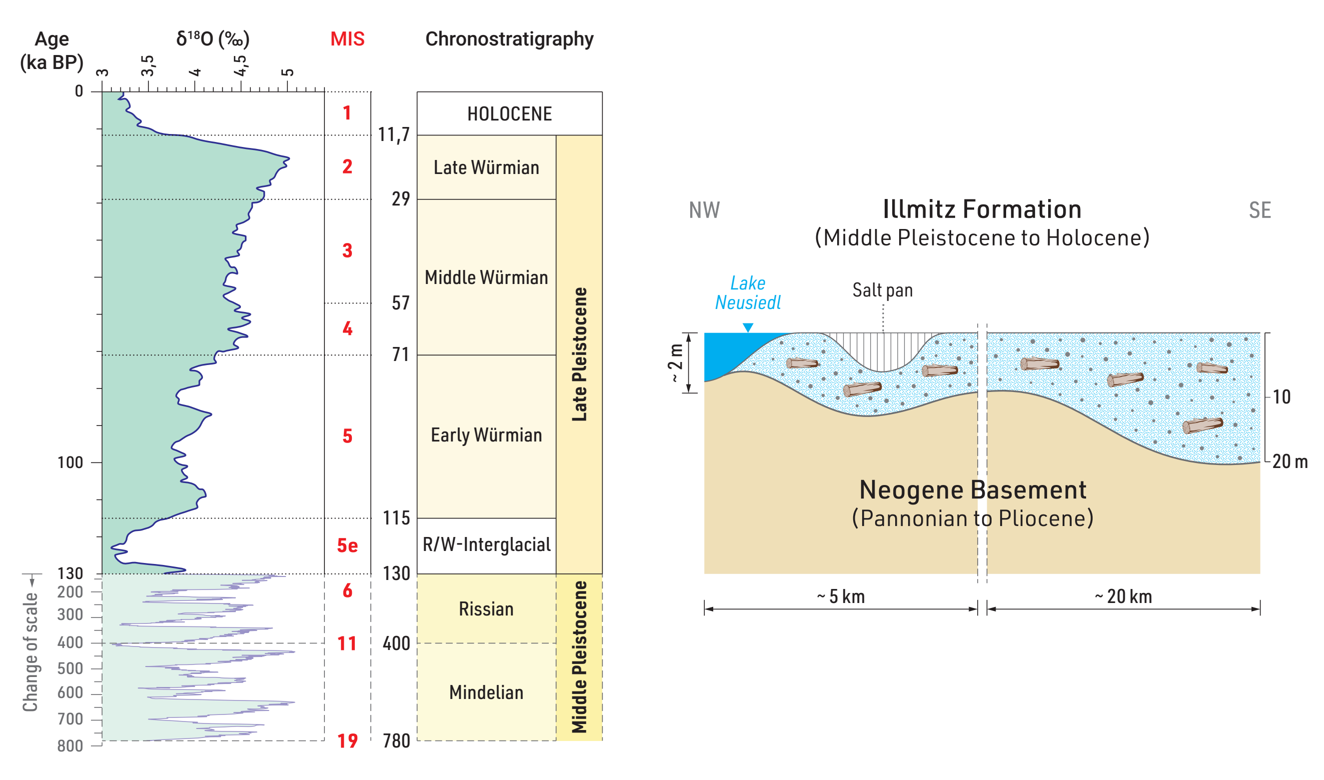

Figure 3: Tentative schematic sketch of Quaternary deposits southeast of Lake Neusiedl. The Rissian to Holocene deposits of the Illmitz Formation with its wood remains unconformably overlie the Neogene basement of the western Danube Basin. Stratigraphy of the Illmitz Formation modified from Häusler et al. (2021b). Marine oxygen isotope stages (MIS) after Lisiecki and Raymo (2005). For Würmian chronostratigraphy the classification of Stojakowits et al. (2021) was used.

was termed "Blaue Serie" that is overlain by the "Gelbe Serie" (Häusler, 2007). The latter is unconformably overlain by fine- and coarse-clastic sediments dated to the Pleistocene. Reconstruction of Danube paleogeography by Fink (1960) and Fink et al. (1966) revealed that since Pannonian times paleo-Danube flowed from the southern Vienna Basin through a southeast-trending depression (of today´s village of Parndorf) toward the Kisalföld. Due to tectonic displacements (probably during the Mindelian/Rissian Interglacial period; ~MIS 11; ~400 ka; Fig. 3), the Parndorf Depression was relatively lifted compared to the neighbouring Seewinkel Plain. When the Parndorf Plateau was overturned in southern direction it loomed several meters higher to the north. As a result, paleo-Danube changed its course from the "Bruck Gate" (of today´s village Bruck/Leitha) about 10 km northeast to the "Devin Gate" of River Morava (of today´s Devín, a borough of Bratislava) and flowed clockwise around the elevated Parndorf Plateau. The Early Pleistocene to Mindelian fluvial deposits of paleo-Danube which were preserved on the elevated Parndorf Plateau are referred to as the Parndorf Formation (Häusler et al., 2021b). Where at the southeastern slope of the Parndorf Plateau Mindelian deposits crop out (Fuchs, 1985) Zámolyi et al. (2017) dated fine-grained deposits to >300 ka.

The Quaternary deposits of the Seewinkel Plain previously were mapped as "Seewinkelschotter" and dated as deposits of Würmian Glaciation by Fuchs (1985). Indirectly and directly dated by Häusler et al. (2021b) these deposits were defined as Illmitz Formation ranging from Rissian to Holocene. Indirect dating of the Illmitz Formation was gained twofold. First, by regional comparison of the "Seewinkelschotter" with channel deposits from Rissian glaciation in the neighbouring Kisalföld (Jánossy and Krolopp, 1994; Häusler, 2007; Rohatsch and Häusler, 2017). The second strong argument for its Rissian age follows the suggestion of Franz and Husz (1961) who concluded that a gravelly silt rich in soluble salts was deposited in a fluvio-lacustrine environment during the climatically warmer period of the Rissian/Würmian Interglacial (MIS 5e) some ~130 to ~115 ka ago. The formation of saline soils and of the salt pans of the Seewinkel can be attributed to this salt-bearing horizon (Häusler et al., 2021b). The find of a molar of a straight-tusked elephant on top of a gravel pit in the southern Seewinkel (Häusler, 2017) also suggests warmer climatic conditions there, probably during an interstadial of MIS 5. Plant remains from salt pans at a depth of just 1.5 meters were radiocarbon dated ranging from ~37 000 cal BP to ~8 000 cal BP (Häusler et al., 2021b). Consequently, the gravelly silt of the salt-bearing horizon as well as layers of silt and clay, several meters in thickness represent a time span from MIS 5e to Holocene. In addition, optically stimulated luminescence data of fine-grained deposits on top of gravel pits in the Seewinkel Plain ranging from 100 to 55 ka suggest that they were deposited from Early to Middle Würmian (Häusler et al., 2021b; Zámolyi et al., 2017). The subdivision of the Late Pleistocene used in Fig. 3 is based on Stojakowits et al. (2021). Accordingly, the Early Würmian corresponds to MIS 5d-a (115–71 ka), the Middle Würmian to MIS 4 (71–57 ka) and MIS 3 (57–29 ka), and the Late Würmian to MIS 2 (29–11.7 ka). The Late Pleistocene ended with the termination of the Younger Dryas, some 11 700 years ago when the Holocene Epoch began. The Holocene chronostratigraphy of sudden avulsion events of the Danube and of the Tisza/Maros rivers in southeastern Hungary is interpreted based on geochronological evidence of wood finds in riverine deposits using the classification of Mangerud et al. (1974).

In terraces of the Tullner Feld west of Vienna, at a depth of six meters, remains of birch trunks and up to 10 meters long trunks of pines were dated ~10 000 BP to ~9 000 BP (Piffl, 1971). Hence these trees were displaced by avulsion events of River Danube in Preboreal. Residues from mixed forests with oak and elm from floodplains of the upper Danube catchment indicate further major avulsion events from Boreal (~9 000 BP to ~8 000 BP) to Atlantic (~8 000 BP to ~5 000 BP; (Becker, 1978)). A major flood event during Boreal is also reported from the Danubian Lowlands (Podunajská nížina) of neighbouring Slovakia. During construction of the Gabčíkovo power plant in the 1980s, at a depth of 10–16 meters, a 12 m long oak trunk was excavated that was dated to ~8 138 ± 50 BP (Kúdela and Reinprecht, 1990). Kolář and Rybníček (2011) and Kern et al. (2022) reported similar large avulsion events during Boreal and Atlantic from the catchment of the Tisza and Maros rivers in southeastern Hungary. Satellite images of the confluence of Danube and Morava show that south of Bratislava the Little Danube (Moson Duna of Szigetköz) meanders southeastwards to Mosonmagyaróvár and further to Győr. Since no comparable geomorphic unit of a sinuous channel belt extends into the Seewinkel, it can be assumed that the Danube no longer flowed into the Seewinkel in the Holocene. Only when the Danube flooded the Kisalföld of today's Győr county did backwaters probably arise in the tributary rivers Rabnitz and Raab that flooded the Hanság and the Seewinkel (Häusler et al., 2021b). As a result, fine-grained deposits of the western Seewinkel dated ~12 000 cal BP to ~8 100 cal BP (Häusler et al., 2021b) suggest such temporary floods from Late Würmian to Holocene.

In summary, it can be stated that the Quaternary deposits of the Seewinkel Plain, the thickness of which increases from the shore of Lake Neusiedl towards Kisalföld up to 20 meters (Fig. 3), cover a period from Rissian to Holocene. In contrary to the adjacent Vienna Basin in the northwest and the Kisalföld Basin in the southeast, both of which subsided several hundreds of meters along faults (Halouzka, 1998; Scharek, 2000; Zámolyi et al., 2017), the Neogene basement of the Seewinkel Plain remained relatively stable during Pleistocene.

To date, only a few wood finds from the coarse-clastic Illmitz Formation were radiocarbon dated (Table 1). Actually, it is incomprehensible why Quaternary deposits of this UNESCO World Heritage Site never have been investigated in detail and only few local data provide specific information on their stratigraphy. To obtain a better insight into the contemporaneous deposition of lacustrine deposits beneath salt pans and neighbouring channel deposits further investigations of wood samples dredged from groundwater-filled gravel pits in the Seewinkel Plain were implemented.

3. Material and methods

For the systematic collection of wood residues, satellite images of gravel pits were selected that showed current gravel mining. In addition, former larger gravel pits were visited which were marked in the geological map 1:50 000 by Fuchs (1985). A total 15 gravel pits were inspected. Wood samples for identifying species and radiocarbon dating were collected from the following eight gravel pits (Fig. 1b):

- GP1: Gravel pit of Steiner company southeast of Podersdorf am See (operating in 2016).
- GP2: Gravel pit south of Frauenkirchen (sampling before 2009; in 2016 recreation area of St. Martins Therme & Lodge).
- GP3: Gravel pit Langäcker of Pinetz company northeast of east-southeast of Frauenkirchen (operating in 2016).
- GP4: Gravel pit Briefhäusl of Kirschner company east-southeast of Halbturn (operating in 2016).
- GP5: Gravel pit Göglhof of Kirschner company east-southeast of Halbturn (operating in 2016).
- GP6: Former gravel pit west of Andau (in 2016 recreation area).
- GP7: Gravel pit of Koppi company northeast of Wallern im Burgenland (operating in 2016).
- GP8: Former gravel pit of Koppi company northeast of Pamhagen (recreation area in 2016).

In 2016, from over 100 selected wood finds, 20 samples were selected for identifying the wood species and 12 samples for radiocarbon dating.

3.1. Radiocarbon dating of wood remains

Radiocarbon dating of the samples collected in 2016 was performed at the VERA (Vienna Environmental Research Accelerator) laboratory of the University of Vienna. The samples were pretreated with our standard ABA (acid-base-acid) method and further processed as described in Wild et al. (2008). No cellulose extraction was performed, as it is expected that possible contaminations such as carbonates, fulvo and humic acids are removed with the ABA method. The reference materials IAEA C-3, C-5, C-6 (Rozanski et al., 1992) and NOX (NIST-SRM-4990C) and the blank material (graphite or black coal) were chemically pretreated largely in the same way and in par-

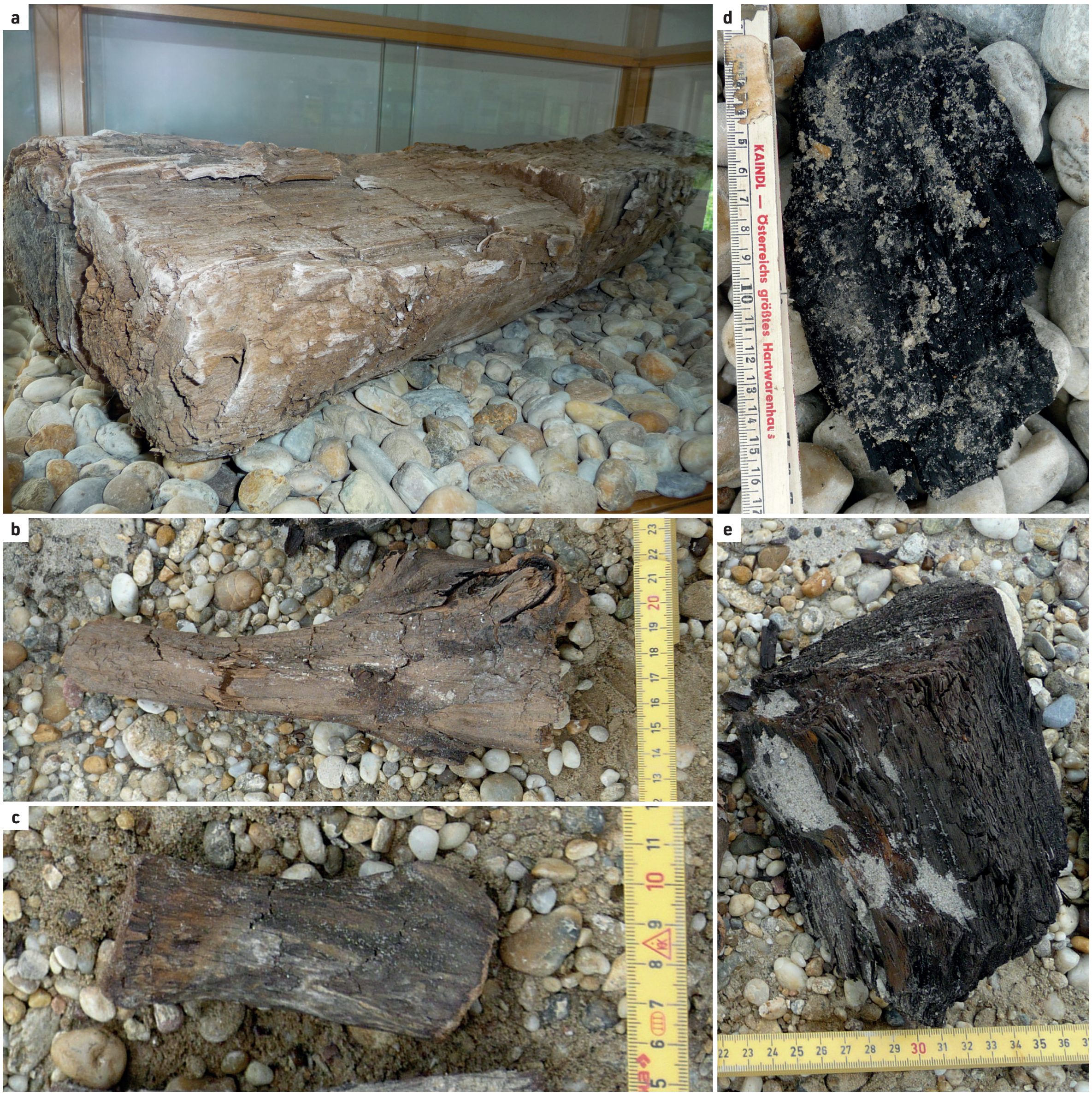

Figure 4: (a) This trunk, formerly exhibited in the Information Center of the Lake Neusiedl - Seewinkel National Park, was dredged in gravel pit GP1 southeast of Podersdorf am See. It was identified as pine by Georg Grabherr (University of Vienna) and dated to ~50 000 uncalibrated years BP (Table 1: sample 2011; Anonymus, 2015). **(b)** Subrounded pieces of wood (H2016-30/03, ~6*20 cm in size) from gravel pit Göglhof of Kirschner company, 3.5 km northeast of St. Andrä am Zicksee (GP5). The wood was identified as *Pinus* sp. (pine; Fig. 5a-b). **(c)** Piece of subrounded wood (H2016-30/02, ~4*10 cm in size) from same gravel pit GP5. The wood was identified as *Fraxinus excelsior* (ash; Fig. 5d-e). This piece of wood was dated to >52 500 BP (VERA-6375, Table 2). **(d)** Piece of subrounded coalified wood (H2016-23/06, ~14*8 cm in size) from gravel pit GP7 northeast of Wallern im Burgenland with remains of a fine sandy matrix. **(e)** Piece of subrounded coalified wood (H2016-30/04, ~10*10 cm in size) from gravel pit GP5 Göglhof of Kirschner company, 3.5 km northeast of St. Andrä am Zicksee with remains of a fine sandy matrix. This wood was identified as *Quercus* sp. (oak; Fig. 5f).

allel to the samples. The consistency of the ^{14}C-values of the reference materials and the long-term stability of the blank values served as internal quality control. In addition, the reliability of our method was checked by participating in several intercomparison exercises (Scott et al., 2017). The ^{14}C determination was performed according to the measurement protocol given in Steier et al. (2004). The results of the investigations are listed in Table 2. Given uncertainties of the δ^{13}C-values and the ^{14}C-ages are 1σ-values. The δ^{13}C-values were determined with the accelerator mass spectrometry (AMS) system.

3.2. Wood species analysis

To identify the wood species of samples dredged from gravel pits of the Seewinkel Plain, small samples were soaked with water to soften the tissue, as they were completely dry. Then sufficiently soft samples were orientated to find the square section and cut with a razor blade to sections (= very thin slices). These sections were investigated with a transmission light microscope and relevant areas were documented by microphotography. If necessary, slices from tangential and radial sections were also analysed and documented. To identify anatomical

Location	Gravel Pit	Coordinates	Sample	Lab.-Nr.	δ13C (‰)	14C-age (years BP)
Gravel pit of Steiner company north of Illmitz	**GP1**	47° 49′ 41.80″ 16° 51′ 17.72″	H2016-04/01	VERA-6371	−23.7 ± 3.0	> 52,300
Gravel pit of Steiner company north of Illmitz	**GP1**	47° 49′ 41.80″ 16° 51′ 17.72″	H2016-04/04	VERA-6372	−17.9 ± 4.0	> 48,800
Gravel pit Langäcker of Pinetz company northeast of Frauenkirchen	**GP3**	nd	ED04/NS/1	VERA-3461	−27.4 ± 0.3	> 50,800
Gravel pit Langäcker of Pinetz company northeast of Frauenkirchen	**GP3**	47° 50′ 44.35″ 16° 56′ 10.80″	P2004-2	MAMS 24592*	−18.8	> 50,000
Gravel pit Briefhäusl of Kirschner company, 3.5 km SE of Halbturn	**GP4**	47° 50′ 16.80″ 17° 01′ 16.68″	H2016-10/01	VERA-6379	−26.6 ± 2.3	> 50,100
Gravel pit Briefhäusl of Kirschner company, 3.5 km SE of Halbturn	**GP4**	47° 50′ 14.74″ 17° 01′ 19.90″	H2016-31/01	VERA-6376	−22.0 ± 1.3	> 44,500
Gravel pit Göglhof of Kirschner company, 3.5 km NE of St. Andrä am Zicksee	**GP5**	47° 48′ 40.81″ 16° 57′ 51.07″	H2016-30/01	VERA-6374	−20.2 ± 5.1	> 52,500
Gravel pit Göglhof of Kirschner company, 3.5 km NE of St. Andrä am Zicksee	**GP5**	47° 48′ 40.81″ 16° 57′ 51.07″	H2016-30/02	VERA-6375	−27.5 ± 0.7	> 52,500
Gravel pit of Koppi company, 1.5 km NE Wallern im Burgenland (western pit)	**GP7**	47° 42′ 06.91″ 16° 56′ 39.73″	H2016-03/01	VERA-6370	−39.6 ± 0.8	> 52,200
Gravel pit of Koppi company, 1.5 km NE Wallern im Burgenland (western pit; deposited in eastern pit of Steiner company)	**GP7**	47° 42′ 06.91″ 16° 56′ 39.73″	H2016-23/03	VERA-6373	−31.3 ± 0.8	> 52,000
Gravel pit Koppi company, 1.5 km NE Wallern im Burgenland (north-western pit; sample Roland Mayer, University of Vienna)	**GP7**	47° 44′ 20.61″ 16° 56′ 54.50″	H2016-40/01	VERA-6377	−38.6 ± 1.5	> 51,900
Gravel pit of Koppi company, 2 km NE Pamhagen	**GP8**	47° 42′ 06.91″ 16° 56′ 39,73″	H2016-01/01	VERA-6378	−22.3 ± 1.4	> 51,200
Gravel pit of Koppi company, 2 km NE Pamhagen	**GP8**	47° 42′ 05.52″ 16° 56′ 39.84″	H2016-01/02	VERA-6369	−29.6 ± 1.4	> 52,500

Table 2: Minimum ^{14}C-ages and δ^{13}C-values of wood sampled in gravel pits of the Seewinkel Plain (VERA laboratory code of Vienna Environmental Research Accelerator-Laboratory; * laboratory code of the Curt-Engelhorn-Zentrum Archäometrie, Heidelberg).

information, we used the atlases of Grosser (1977) and Schweingruber (1990). In some samples anatomical features such as pits, parenchyma and other details were not visible clearly enough as, e.g., in samples H2016-20/03, H2016-23/01, H2016-23/02, H2016-23/03, H2016-23/08 (Table 3) and only allowed for distinguishing between gymnosperms and angiosperms. In other samples the genus was determinable, but not the species (as, e.g., *Pinus* sp., *Quercus* sp., *Ulmus* sp., *Populus* sp., *Salix* sp.) or two species with similar features were not distinguishable from each other (e.g., *Picea/Larix*: both woods show extremely similar anatomical features). Many dark-coloured samples underwent coalification (but were not carbonized) such as samples of H2016-23/04, H2016-23/06, H2016-23/10, H2016-30/04 (Table 3).

4. Results

Majority of the wood samples dredged in gravel pits of the Seewinkel Plain consists of disintegrated small cm- to decimetre-sized brownish pieces of wood (Fig. 2b) and light brown trunks of several meters in length (Fig. 4a). Only a few smaller wood samples showed a dark brown colour (Fig. 4d-e). This chapter first summarizes the radiocarbon dating of selected wood remains and then the identifiable types of wood from gravel pits in the Seewinkel Plain.

4.1. Radiocarbon dating of dredged wood samples

In 2004, a minimum radiocarbon age of >50,800 BP was determined from a find of wood in a gravel pit north-east of Frauenkirchen (GP3: VERA-3461). From the collections in 2016, a further 12 wood samples were analyzed, and - except for sample VERA-6376 (from gravel pit southeast of Halbturn, GP4) - only minimum radiocarbon ages exceeding ~48 000 BP were determined (Table 2). The larger uncertainty of sample VERA-6376 was mainly caused by the scatter of the repeated measurements of the sample, and reduced statistics due to technical problems in the AMS instrument. At the 2σ uncertainty level, it is compatible with an infinite age, but results in a lower minimum age than the other samples.

4.2. Identification of dredged wood samples

The following wood species could be identified from sections of dredged wood samples (Fig. 1b, Table 3): (a) Gymnosperm: conifers such as *Pinus* (pine) and *Picea/Larix* (spruce/larch) and (b) Angiosperm such as *Fraxinus* (ash), *Quercus* (oak), *Ulmus* (elm), *Populus* (poplar) and *Salix* (willow).

***Pinus* sp. (pine):** For a longer period of time, a pine trunk several meters long was exhibited in the Informa-

Gravel Pit	Sample	Wood description
GP1	STEINER 2011	*Pinus* sp. (pine, resin ducts with thin-walled parenchym cells, fenestroid cross-field pits)
GP3	ED2017-3	*Fraxinus excelsior* (ash tree, semi-ring-porous, vessels mostly in pairs)
GP4	H2016-20/01	*Quercus* sp. (oak; ring-porous, latewood vessels in groups, two types of rays)
	H2016-20/03	Angiosperm indet. (diffuse-porous)
	H2016-31/01	*Ulmus* sp. (elm, ring-porous, late-wood vessels in spiral rows)
GP5	H2016-30/01	Wood indet. (cells are no longer visible)
	H2016-30/02	*Fraxinus excelsior* (ash tree)
	H2016-30/03	*Pinus* sp. (pine)
	H2016-30/04	*Quercus* sp. (oak, well preserved, dark brown tissue, beginning coalification)
	H2016-30/05	*Quercus* sp. (oak; ring-porous)
GP7	H2016-23/01	Gymnosperm indet. (tracheids, without resin ducts)
	H2016-23/02	Gymnosperm indet. (without resin ducts)
	H2016-23/03	Angiosperm indet. (diffuse-porous, vessels)
	H2016-23/04	*Salix* sp. (willow) / *Populus* sp. (poplar); (beginning coalification, no ray-cell details)
	H2016-23/06	*Fraxinus excelsior* (ash tree; dark brown, beginning coalification)
	H2016-23/07	*Salix* sp. (willow)
	H2016-23/08	Gymnosperm, *Pinus* sp.? (pine?; resin ducts)
	H2016-23/10	*Fraxinus excelsior* (ash tree); dark brown, beginning coalification
	H2016-40/01	*Populus* sp. (poplar, diffuse-porous, peripheral ray cells axially stretched)
	H2016-45/01	*Fraxinus excelsior* ? (ash tree?)
	H2016-45/02	*Salix* sp.? (willow?, diffuse-porous, peripheral ray cells radially stretched, not well preserved)
	ED2017-1	*Larix decidua* (larch) / *Picea abies* (spruce), cannot be separated on wood-anatomical basis; resin ducts with thick-walled parenchym cells, piceoid crossfield pits
	ED2017-2	*Pinus* sp. (pine)
GP8	H2016-01/2	*Larix decidua* (larch) / *Picea abies* (spruce)

Table 3: Wood description of samples from gravel pits of the Seewinkel Plain GP1-GP8, based on thin sections of wood remains. For location of samples see Figure 1b.

tion Center of the Nationalpark Neusiedler See – Seewinkel which was dated ~50 000 BP (Fig. 4a; Table 1: sample 2011). Wood remains from pines were collected in gravel pits GP2, GP5 and GP7. For original picture of a wood remain with rounded edges from a spruce/larch of sample H2016-30/03 from GP5 see Figure 4b. Figure 5a depicts cross section and Figure 5b depicts radial section of pine of wood sample H2016-30/03 from gravel pit GP5.

***Picea/Larix* sp. (spruce/larch):** Wood remains from a spruce/larch were identified in gravel pit GP7. Figure 5c depicts thin section of *Picea/Larix* (spruce/larch) of sample ED2017-01 from GP7.

***Fraxinus excelsior* (ash):** Wood remains from ash were identified in gravel pits GP3 and GP5. For original piece of wood of sample H2016-30/02 see Figure 4c. Figures 5d-e depict thin sections of *Fraxinus excelsior* (ash) that was dated to >52 200 BP (Table 2).

***Quercus* sp. (oak):** Wood remains from oaks were identified in gravel pits GP4 and GP5. For original sample of coalified piece see Figure 4e. Figure 5f depicts thin section of a well preserved coalified wood sample. In gravel pit GP5 also several meters long oak trunks were identified.

***Ulmus* sp. (elm):** Wood remains of *Ulmus* sp. (elm) only were identified in gravel pit GP4. Figures 6a-b depict cross sections of wood sample H2016-31/01 which was dated to >44 500 BP (Table 2).

***Populus* sp. (poplar):** Wood remains from *Populus* sp. (poplar) were identified in gravel pit GP7. Figure 6c depicts cross section and Figure 6d depicts radial section from wood sample H2016-40/01 which was dated to >51 900 BP (Table 2).

***Salix* sp. (willow):** Wood remains from *Salix* sp. (willow) were identified in gravel pit GP7. Figure 6e depicts cross section and Figure 6f depicts radial section from wood sample H2016-23/07.

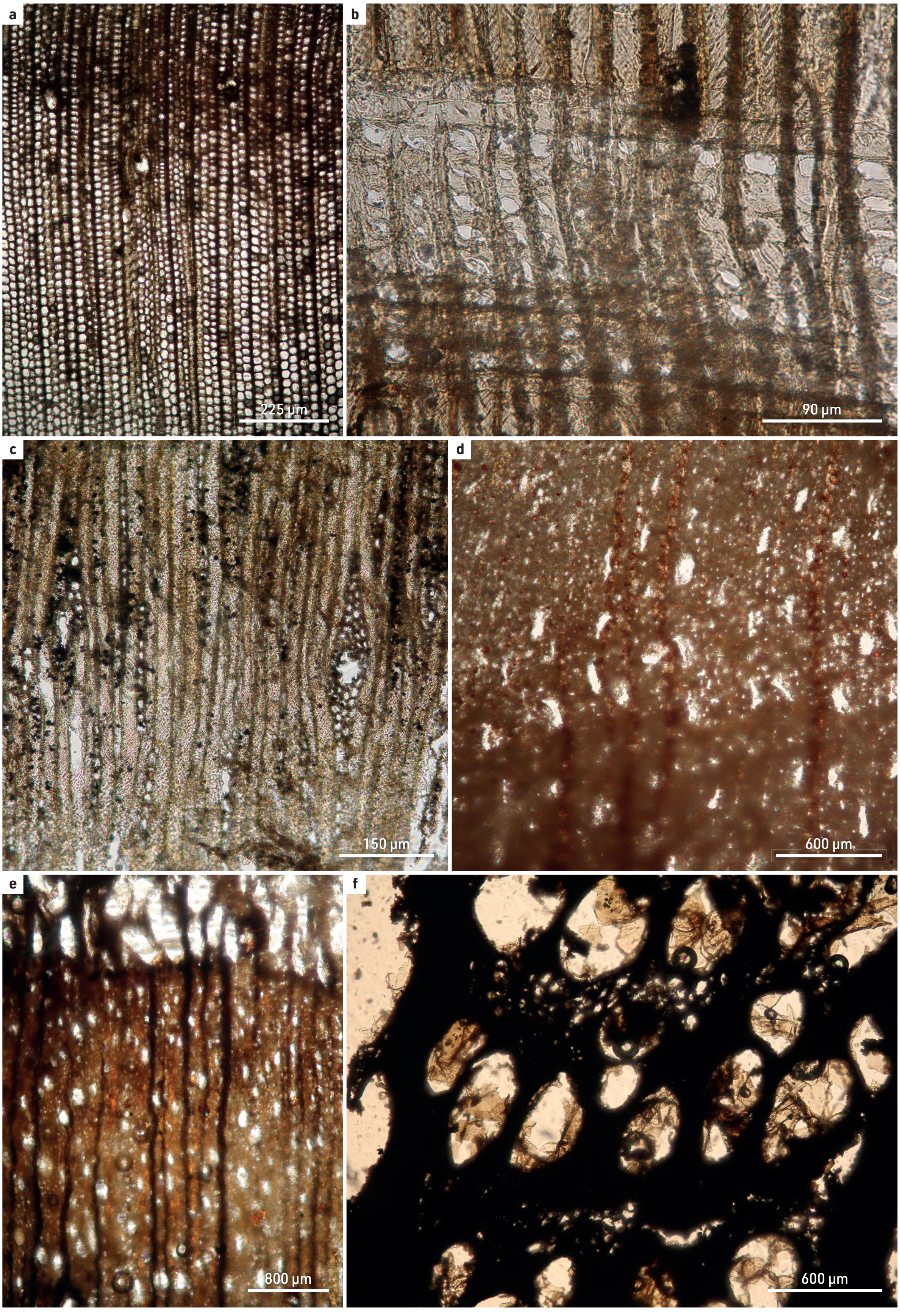

Figure 5: (a) *Pinus* sp. (pine). Cross section of wood sample H2016-30/03 from gravel pit GP5. For original piece of pine see Figure 4b. **(b)** *Pinus* sp. (pine). Radial section of wood sample H2016-30/03 from gravel pit GP5. For original piece of pine see Figure 4b. **(c)** *Picea/Larix* (spruce/larch). Tangential section of wood sample ED2017-01 from GP7. **(d)** *Fraxinus excelsior* (ash). Cross section of compressed wood structure of wood sample H2016-30/02 from gravel pit GP5. **(e)** *Fraxinus excelsior* (ash). Cross section of late wood with ring border, wood sample H2016-30/02 from gravel pit GP5. **(f)** *Quercus* sp. (oak). Cross section of coalified wood sample H2016-30/04 from GP5. For original piece of coalified wood see Figure 4e.

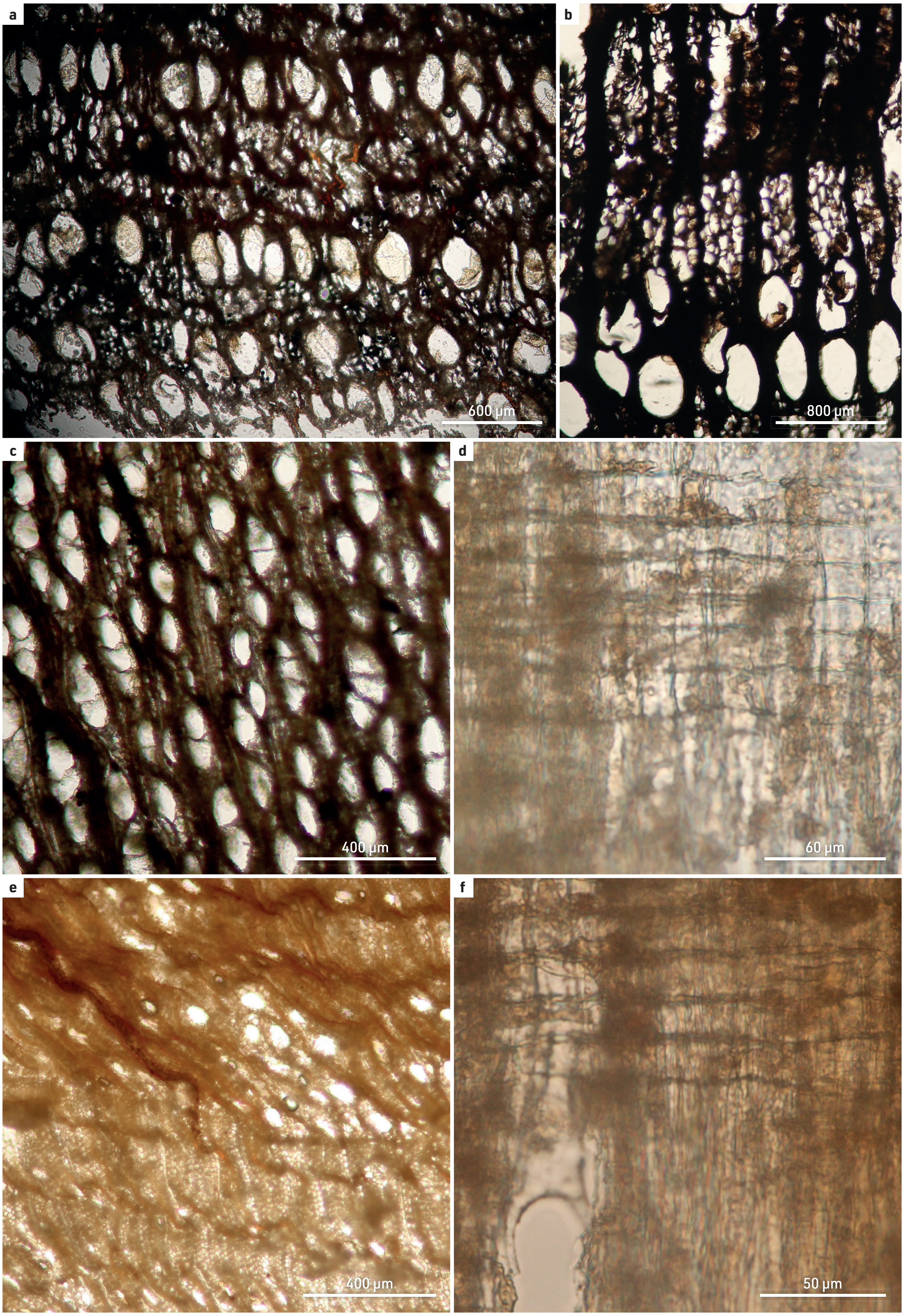

Figure 6: (a), (b) *Ulmus* sp. (elm). Cross section of wood sample H2016-31/01 from gravel pit GP4. **(c)** *Populus* sp. (poplar). Cross section of wood sample H2016-40/01 from GP7. **(d)** *Populus* sp. (poplar). Radial section of wood sample H2016-40/01 from GP7. **(e)** *Salix* sp. (willow). Cross section from wood sample H2016-23/07 from gravel pit GP7. **(f)** *Salix* sp. (willow). Radial section from wood sample H2016-23/07 from gravel pit GP7.

5. Discussion

In this paragraph we discuss three topics related to the investigation of wood samples dredged from groundwater-filled gravel pits of the Nationalpark Neusiedler See - Seewinkel. We first emphasize once again the uncertainty of stratigraphy of Quaternary deposits of the Illmitz Formation (a). Second, we critically characterize the different populations of our wood finds in fluvial deposits of the Seewinkel Plain (b), and third, we describe the extent of coalification of the wood remains and give an interpretation of how possibly the dark brown coalified wood residues of the Seewinkel Plain came into existence (c).

(a) Well-researched outcrops of the Illmitz Formation are rare. Up to now, at an area of ~350 km^2 only few outcrops of alluvial fans were luminescence dated to ~100 to ~55 ka (Häusler et al., 2021b) and four hand-drilled profiles of salt pans were radiocarbon dated ranging from ~40 000 cal BP to ~8 000 cal BP (Häusler et al., 2021b). Radiocarbon dating of dredged wood samples from gravel pits in the Seewinkel yielded two data sets of ^{14}C-ages: one of younger and one of older age. It turned out that three samples collected and analysed from 1988 to 1996 yielded relatively younger uncalibrated ^{14}C-ages ranging between ~37 400 BP and ~28 000 BP which translates to calibrated ages ranging between ~46 800 cal BP and ~34 500 cal BP (Table 1). Thirteen more samples collected since 2016 yielded relatively older minimum ^{14}C-ages exceeding ~50 000 BP (Table 2). One reason for this could be the excavation of deeper and therefore older beds during gravel mining. Basically, the younger set of dredged wood ranging between ~46 800 cal BP and ~34 500 cal BP roughly corresponds to the age of plant remains drilled in salt pans ranging from ~37 000 cal BP to ~34 000 cal BP. The superimposition of the few luminescence dated outcrops of coarse clastic deposits on the gravel thickness map of the Seewinkel (Tauber, 1959) reveals that they match the thickness of the Illmitz Formation of only 5 to 10 meters. The dredged wood remains which are older than ~50 000 BP can in turn be assigned to neighbouring channel deposits that accumulated to a thickness of ~20 meters.

(b) Taken the case that the wood species collected from gravel pits of the Seewinkel Plain represent a stratified context, they suggest two different populations, a swampy lowland forest population and a hilly forest population. The presumably local riparian forest population of the occasionally flooded river valleys contains smaller remains of *Fraxinus* (GP3, GP5) and *Ulmus* (GP4) as well as whole trunks of *Quercus* (GP5). Smaller remains of *Pinus* (GP5) as well as parts of trunks of *Pinus* (GP1 and GP7) might indicate further transport from higher surrounding areas. The finds of *Pinus* trunks with a length of several meters southeast of Podersdorf (GP1: Fig. 4a) and from *Quercus* southeast of Halbturn (GP4: H2016-20/01) suggest enormous avulsion events in the channelized river system of the Illmitz Formation. Relating the regional distribution of dredged trunks with a length of several meters to the thickness of the Illmitz Formation (Tauber, 1959; Zámolyi et al., 2017) reveals that they are associated with gravel deposits reaching maximum thickness of 15–20 m. The coniferous forests of pine, spruce or larch were possibly located at the 30 to 50 m higher hills of the Parndorf Plateau or the hilly catchment area of paleo-Danube upstream. However, such landscape scenario of the Seewinkel Plain is not supported by the radiocarbon age of the wood remains.

c) Whereas peat in the Hanság, southeast of Lake Neusiedl, was deposited few meters in thickness from ~3900 BP to ~280 BP (Häusler et al., 2021a), no thicker peat layers were observed in outcrops of the Illmitz Formation. Only Nelhiebl (1986) reported layers of some cm of peat within a saline soil south of Apetlon and Szadecky-Kardoss (1938) reported isolated occurrences of thin layers of lignite in older Pleistocene gravels from Szombathely south of Győr. Coalification is defined as a transformation of wood and plant material into coal by impact of pressure by overlying layers, temperature, and long time (Teichmüller and Teichmüller, 1954). Early stages of coalification still preserve cell components and anatomical features of the wooden components which by the time collapse and disappear. Moreover, lignite is defined as a brownish-black coal that is intermediate in coalification between peat and subbituminous coal (Jackson, 1997). Van Husen (1981) as well as Irmler and Scholz (2005) described the occurrence of dark layers of organic material within Quaternary gravel beds in Austria and Germany which they termed "Schieferkohle". They interpreted these dark lignite layers resulting from over consolidation of peat-like material, from a formerly thicker sedimentary cover (which might have been eroded in the meantime) or from an advance of local glaciers. However, the Seewinkel Plain was free of glaciers throughout the Quaternary. For geomorphological and stratigraphic reasons, a formerly thicker Illmitz Formation can be excluded. There are finds of coalified brown wood residues (Figs. 4d-e, 5f) for which investigations on geochemical gelification of humic substances (vitrinitisation according to Teichmüller, 1989) are pending. Due to embedding of such pieces of subrounded coalified wood in a sandy-silty matrix which is typical for the base of the Illmitz Formation, natural coalification, and subsequent rounding of the wood fragments by fluvial transport is assumed. Basically, the few coalified remains of Figure 4d-e indicate a much longer residence time in groundwater-saturated fluvial deposits or a completely different chemical environment at the base of the Illmitz Formation than the light brown wood samples had undergone. Whereas Willis et al. (2000) attributed charred tree remains in loess profiles of the last full-glaciation in the Hungarian Lowlands to wildfire, no charred wood remains were detected in the Illmitz Formation. In principle, rounded wood residues of the Illmitz Formation demonstrate a longer transport and resedimentation, as, e.g., Árvai et al. (2018) described from a layer of subfossil driftwood in the Drava River at the Croatian/Hungarian border.

6. Conclusion

The synoptic evaluation of the few litho- and biostratigraphic as well as radiocarbon and luminescence data of the Illmitz Formation leads to the reconstruction of the following individual steps of the Seewinkel landscape from the Holocene back to the Rissian/Würmian Interglacial. Plant relics from youngest fine-grained lacustrine deposits below salt pans near Podersdorf am See yielded radiocarbon ages ranging from ~12 000 cal BP to ~8 000 cal BP (Häusler et al., 2021b). Comparable young wood remains in channel deposits could not be dated anywhere in the Seewinkel. Therefore, the up to now youngest known flooding events during which wood remains were deposited in the coarse-clastic Illmitz Formation range from ~46 000 cal BP to ~34 000 cal BP (Table 1). These flooding events during MIS 3, in turn, correspond to the age of plant relics in lacustrine deposits beneath salt pans near St. Andrä am Zicksee which were dated, e.g., to ~37 000 cal BP (Häusler et al., 2021b). Hence, it can be concluded that during late Middle Würmian both fluvial and lacustrine sediments were deposited in the Seewinkel Plain. Most of the dredged wood remains, however, yielded minimum radiocarbon ages exceeding ~50 000 years (Table 2).

As described in the geological settings, the salt-bearing horizon underlying the salt pans of the western Seewinkel as well as the luminescence dated beds on top of gravel pits represent older deposits of the Illmitz Formation. Therefore, it can be concluded that the variety of wood residues deposited in the up to 20 meters thick sandy gravels between the salt-bearing horizon and the luminescence dated beds were probably deposited between ~130 and ~55 ka. In terms of climatic conditions, an assignment of the few investigated wood taxa from the gravel pits of the Seewinkel to glacial/stadial or interglacial/interstadial periods remains very speculative since willow, pine and larch are climatically indifferent and only elm, ash and oak are thermophilic. In addition, Hošek et al. (2024) proofed that discharge of thermal water in southern Moravia (Czech Republic) and in the Liptov Basin of the Western Carpathians (Slovak Republic) maintained a humid and warm microclimate and therefore thermophilous tree species survived the Last Glacial Maximum (LGM) there. Since thermal springs are also known from the northwest and southeast slopes of the Leitha Mountains (Häusler, 2023), the presence of warm microclimatic areas during the LGM in the northern Seewinkel Plain cannot be ruled out. Due to the lack of Holocene radiocarbon ages for wood remains dredged from the gravel pits of the Seewinkel it can be supposed that oak remains obtained from gravel pits GP4 and GP5 (Table 3, Fig. 5f) cannot be attributed to deciduous temperate zone forests of the Atlantic period, the Holocene climatic optimum with its thermal maximum around 8000 years BP.

Acknowledgements

Field studies and dating of samples were supported by the Office of the Federal State of Burgenland. Sampling of wood in gravel pits was kindly permitted by Rudolf Kirschner (Mönchhof), Leopold Koppi (Pamhagen), Josef Pinetz (Frauenkirchen) and Alois Steiner (Illmitz). ^{14}C-data from samples collected before the year 2000 were provided by Franz Sauerzopf (Rust: VRI-1019), Franz Klein (Illmitz: VERA- 5874), and by Julian Pistotnik (Vienna: VRI-1832) respectively. We thank Andreas Rohatsch (Technical University of Vienna), Erich Draganits and Roland Mayer (University of Vienna) for providing additional samples from various gravel pits of the Seewinkel. Two anonymous reviewers are highly acknowledged for their very constructive reviews and valuable suggestions. Finally, we would like to thank Gerhard Draxler (University of Vienna) for critical review of microphotographs of wood samples presented in this paper.

References

Anonymus, 2015. Altes Holz - Geschichte im tiefen Schotter. Geschnatter (Nationalparkzeitung Neusiedlersee-Seewinkel), 3, 4.

Árvai M., Antalfi E., Sebe K., Mihály E., Fehér S., Kern Z., 2018. A Dráva durvaszemcsés folyóvízi üledékéből előkerült szubfosszilis uszadékfák dendrokronológiai és faanatómiai vizsgálata (Wood anatomy and dendrochronology of subfossil driftwood in alluvial deposits of the Drava River). A Kaposvári Rippl-Rónai Múzeum Közleményei, 5, 5–14. https://doi.org/10.26080/krrmkozl.2018.5.5

Becker B., 1978. Beiträge zur postglazialen Landschaftsentwicklung des Donautales. In: Nagl, H. (Hrsg.) Beiträge zur Quartär- und Landschaftsforschung (Festschrift zum 60. Geburtstag von Julius Fink), 23–35, Hirt, Wien.

Bronk Ramsey C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon, 51/1, 337–360.

Fink J., 1960. Leitlinien der österreichischen Quartärstratigraphie. Mitteilungen der Geologischen Gesellschaft in Wien, 53, 249–266.

Fink J., Banu A.C., Brunnacker K., Fotakiewa E., Graul H., Kohl H., Krippel E., Riedl H., Pécsi M., 1966. Die Paläogeographie der Donau. In: Liepold, R. (Hrsg.) Limnologie der Donau, III+IV, Lieferung 2, Stuttgart, 50 pp.

Fischer I., 1993. Dokumentation der österreichischen Ramsar-Gebiete. Gebiete gemäß dem "Übereinkommen über Feuchtgebiete, insbesondere als Lebensraum für Wasser- und Watvogel, von internationaler Bedeutung" (Ramsar-Konvention), UBA-93-076, Umweltbundesamt, Wien, 44 pp.

Franz H., Husz G., 1961. d) Hackelsberg - Neusiedl a. See - Podersdorf - Illmitz. In: Franz H., Husz G., Das Neusiedlerseebecken (Exkursion C). Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft, 6, 57–62.

Fuchs W., 1985. Geologische Karte der Republik Österreich 1:50.000, Blatt 79 Neusiedl am See, 80 Ungarisch Altenburg, 109 Pamhagen, Geologische Bundesanstalt, Wien.

Grosser D., 1977. Die Hölzer Mitteleuropas. Ein mikrophotographischer Lehratlas. Reprint der 1. Auflage von 1972, Verlag Kessel, Remagen, 218 pp.

Halouzka R., 1998. Neotectonic Map 1: 200 000 of the Danube Regional Environmental Geology Program, Geological Institute of Hungary, Budapest.

Harzhauser M., Landau B., Mandic O., Neubauer T.A., 2024. The Central Paratethys Sea – rise and demise of a Miocene European marine diversity hotspot. Scientific Reports, https://doi.org/10.1038/s41598-024-67370-6

Harzhauser M., Piller W.E., 2005. Neogen des Wiener Beckens. 75. Jahrestagung der Paläontologischen Gesellschaft, Graz, 42 pp.

Häusler H. (ed.), 2007. Erläuterungen zur geologischen Karte der Republik Österreich 1:50 000, Blatt 79 Neusiedl am See, 80 Ungarisch-Altenburg, 109 Pamhagen. Geologische Bundesanstalt, Wien, 88 pp.

Häusler H., 2017. *Elephas antiquus* - Sensationsfund eines quartären Waldelefanten im Seewinkel. Geschnatter (Nationalparkzeitung Neusiedlersee-Seewinkel), 60/1, 1–2.

Häusler H., 2023. Zur Hydrogeologie der schwebenden Grundwasserkörper unter den Salzlacken des Seewinkels (Nördliches Burgenland, Österreich). Berichte der GeoSphere Austria, 145, 152 pp.

Häusler H., Kovács G., Wild E.M., Steier P., Heil B., 2021a. The Osli Formation - a Holocene lithostratigraphic unit in the Danube/Kisalföld Basin, eastern Austria and northwestern Hungary. Austrian Journal of Earth Sciences, 114, 69–87. https://doi.org/10.17738/ajes.2021.0005

Häusler H., Wild E.M., Steier P., 2021b. Alter und Fazies der quartären Ablagerungen in der Umgebung des Neusiedler Sees (Nördliches Burgenland, Österreich). Jahrbuch der Geologischen Bundesanstalt, 161, 5–28.

Hodits B., 2006. Interpretation hochfrequenter Seeseismik und 3-D Strukturmodellierung im Neusiedler See (Österreich). Master Thesis, Universität Wien, Austria, 69 pp. https://www.academia.edu/114287849/Diplomarbeit_B_Hodits

Hošek J., Pokorný P., Storch D., Kvaček J., Havig J., Novák J., Hájková P., Jamrichová E., Brengman L., Radoměřský T., Křížek M., Magna T., Rapprich V., Laufek F., Hamilton T., Pack A., Di Rocco T., Horáček I., 2024. Hot spring oases in the periglacial desert as the Last Glacial Maximum refugia for temperate trees in Central Europe. Science Advances, 10/22, 1–14. https://doi.org/10.1126/sciadv.ado6611

Irmler R., Scholz H., 2005. Belegt der Fund einer "Schieferkohle" die spätglaziale Vergletscherung der Immenstädter Nagelfluhberge? Eiszeitalter und Gegenwart, 55, 88–101. https://doi.org/10.3285/eg.55.1.05

Jackson J.A. (ed.), 1997. Glossary of Geology. Fourth edition, American Geological Institute, Alexandria, Virginia, 769 pp.

Jánossy D., Krolopp E., 1994. Lower Pleistocene mollusc and vertebrate fauna from the gravel pit of Győrújfalu (NW Hungary). Földtani Közlöny, 124/4, 403–440.

Kern Z., Árvai M., Urdea P., Timofte F., Antalfi E., Fehér S., Bartyik T., Sipos G., 2022: First report on dendrochronological and radiocarbon studies of subfossil driftwood recovered across the Mureş/Maros Alluvial Fan. Central European Geology, 65, 40–48. https://doi.org/10.1556/24.2021.00120

Kolář T., Rybníček, M., 2011. Dendrochronological and radiocarbon dating of subfossil wood from the Morava River basin. Geochronometria, 38/2, 155–161. https://doi.org/10.2478/s13386-011-0021-x

Kúdela J., Reinprecht L., 1990. Einfluß der Holzfeuchte auf die Druckfestigkeit von rezentem und subfossilem Eichenholz (*Quercus robur* L.). Holzforschung, 44/3, 211–215. https://doi.org/10.1515/hfsg.1990.44.3.211

Lisiecki L.E., Raymo M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. Paleoceanography, 20, 1–17. https://doi.org/10.1029/2004pa001071

Magyar I., Radivojević D., Szantó O., Synak R., Ujszászi K., Pócsik M., 2013. Progradation of the paleo-Danube shelf margin across the Pannonian Basin during the Late Miocene and Early Pliocene. Global and Planetary Change, 103, 168–173. https://doi.org/10.1016/j.gloplacha.2012.06.007

Mangerud J., Andersen S.T., Berglund B.E., Donner J.J., 1974. Quaternary stratigraphy of Norden, a proposal for terminology and classification. Boreas, 3, 109–128. https://doi.org/10.1111/j.1502-3885.1974.tb00669.x

Nelhiebl P., 1986. Erläuterungen zur Bodenkarte 1:25.000 Kartierungsbereich Neusiedl am See-Süd (KB 139). Bundesanstalt für Bodenwirtschaft, Wien, 227 pp.

Piffl L., 1971. Zur Gliederung des Tullner Feldes. Annalen des Naturhistorischen Museums in Wien, 75, 292–310.

Reimer P.J., Austin W.E.N., Bard E., Bayliss A., Blackwell P.G., Bronk Ramsey C., Butzin M., Cheng H., Edwards R.L., Friedrich M., Grootes P.M., Guilderson T.P., Hajdas I., Heaton T.J., Hogg A.G., Hughen K.A., Kromer B., Manning S.W., Muscheler R., Palmer J.G., Pearson C., van der Plicht J., Reimer R.W., Richards D.A., Scott E.M., Southon J.R., Turney C.S.M., Wacker L., Adolphi F., Büntgen U., Capano M., Fahrni S.M., Fogtmann-Schulz A., Friedrich R., Köhler P., Kudsk S., Miyake F., Olsen J., Reinig F., Sakamoto M., Sookdeo A., Talamo S., 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radiocarbon, 62/4, 725–757. https://doi.org/10.1017/RDC.2020.41

Reimer P.J., Brown T.A., Reimer R.W., 2004. Discussion: Reporting and calibration of post-bomb 14C data. Radiocarbon, 46/3, 1299–1304. https://doi.org/10.1017/S0033822200033154

Rohatsch A., Häusler H., 2017. *Bovis schoetensaki* – ein eiszeitlicher Steppenbison aus dem Seewinkel. Geschnatter (Nationalparkzeitung Neusiedlersee-Seewinkel), 60/2, 1.

Rozanski K., Stichler W., Gonfiantini R., Scott E.M., Beukens R.P., Kromer B., van der Plicht J., 1992. The IAEA ^{14}C Intercomparison Exercise 1990. Radiocarbon, 34/3, 506–519. https://doi.org/10.1017/S0033822200063761

Scharek P. (ed.), 2000. Neotectonic Map. Jahrbuch der Geologischen Bundesanstalt, 142 (Danube Region Environmental Geology Programme DANREG - Explanatory notes), 483–492.

Schweingruber F.H., 1990. Anatomie europäischer Hölzer: ein Atlas zur Bestimmung europäischer Baum-, Strauch- und Zwergstrauchhölzer (Anatomy of European woods: an atlas for the identification of European trees, shrubs and dwarf shrubs), Haupt, Bern, 800 pp.

Scott E.M., Naysmith P., Cook G.T., 2017. Should archaeologists care about ^{14}C intercomparisons? Why? A summary report on SIRI. Radiocarbon, 59/5, 1589–1596. https://doi.org/10.1017/RDC.2017.12

Steier P., Dellinger F., Kutschera W., Priller A., Rom W., Wild E.M., 2004. Pushing the precision limit of ^{14}C AMS. Radiocarbon, 46/1, 5–16. https://doi.org/10.1017/S0033822200039291

Stojakowits P., Mayr C., Ivy-Ochs S., Preusser F., Reitner J.-M., Spötl C., 2021. Environments at the MIS 3/2 transition in the northern Alps and their foreland. Quaternary International, 581–582, 99–113. https://doi.org/10.1016/j.quaint.2020.08.003

Szadecky-Kardoss E., 1938. Geologie der rumpfungarländischen Kleinen Tiefebene mit Berücksichtigung der Donaugoldfrage. Sopron, 444 pp.

Tauber A.F., 1959. Geologische Stratigraphie und Geschichte des Neusiedlerseegebietes. Wissenschaftliche Arbeiten aus dem Burgenland, 23 (Landschaft Neusiedlersee), 18–24.

Teichmüller M., 1989. The genesis of coal from the viewpoint of coal petrology. In: Lyons P.C., Alpern B., (eds.) Peat and coal: origin, facies, and depositional models. Reprint from the International Journal of Coal Geology, 12, Elsevier, Amsterdam, 87 pp.

Teichmüller, M., Teichmüller, R., 1954. Die stoffliche und strukturelle Metamorphose der Kohle. Geologische Rundschau, 42, 265–296. https://link.springer.com/article/10.1007/BF01773966

Van Husen D., 1981. Geologisch-sedimentologische Aspekte im Quartär von Österreich. Mitteilungen der Österreichischen Geologischen Gesellschaft, 74/75, 197–230.

Wild E.M., Neugebauer-Maresch C., Einwögerer Th., Stadler P., Steier P., Brock F., 2008. ^{14}C-Dating of the Upper Paleolithic Site at Krems-Hundssteig in Lower Austria. Radiocarbon, 50/1, 1–10. https://doi.org/10.1017/S0033822200043332

Willis J., Rudner E., Sümegi P., 2000. The full-glacial forests of Central and Southeastern Europe. Quaternary Research, 53, 203–213. https://doi.org/10.1006/qres.1999.2119

Zámolyi A., Salcher B., Draganits E., Exner U., Wagreich M., Gier S., Fiebig M., Lomax J., Surányi G., Diel M., Zámolyi F., 2017. Latest Pannonian and Quaternary evolution at the transition between Eastern Alps and Pannonian Basin: new insights from geophysical, sedimentological and geochronological data. International Journal of Earth Sciences, 106, 1695-1721. https://doi.org/10.1007/s00531-016-1383-3

Received: 15.9.2024
Accepted: 5.2.2025
Editorial Handling: Sylke Hilberg