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RESEARCH ARTICLE

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Mid- to Late Holocene landscape dynamics and rural settlement in the uplands of northern Bavaria, Germany

Katja Kothieringer[1] | Timo Seregély[2] | Doris Jansen[3] | Raphael Steup[4] | Andreas Schäfer[2] | Karsten Lambers[5] | Markus Fuchs[4]

[1]Digital Geoarchaeology, University of Bamberg, Bamberg, Germany

[2]Pre- and Protohistoric Archaeology, University of Bamberg, Bamberg, Germany

[3]Jansen & Rickert, Neumünster, Germany

[4]Department of Geography, University of Giessen, Giessen, Germany

[5]Faculty of Archaeology, Leiden University, Leiden, The Netherlands

Correspondence

Karsten Lambers, Faculty of Archaeology, Leiden University, Leiden, The Netherlands.
Email: k.lambers@arch.leidenuniv.nl

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Abstract

We present results from a systematic interdisciplinary study on (pre-)historic rural settlement and landscape development in an upland region of northern Bavaria, Germany. The archaeological and geoarchaeological investigations—supported by radiocarbon dating, optically stimulated luminescence dating, and palaeoecological analysis—were performed to (i) identify so far unknown prehistoric rural settlement sites, (ii) determine site-specific soil erosion from colluvial deposits, and (iii) assess the composition of woodland from on- and offsite charcoal finds. The earliest indicators of human activities from the Younger Neolithic (late 5th to early 4th millennium B.C.E.) come from colluvial deposits. Our investigations, for the first time, show Middle to Late Bronze Age (ca. 1400–800 B.C.E.), permanent rural settlement in a German central upland region, with a peak in the Late Bronze Age. Due to the varying thicknesses of Bronze Age colluvial deposits, we assume land use practices to have triggered soil erosion. From the spectrum of wood species, Maloideae, ash, and birch are regarded as successional indicators after fire clearance in that period. Settlement continued until the 5th century B.C.E. After a hiatus of 500 years, it re-flourished in the Late Roman and Migration periods (mid-3rd–5th century C.E.) and went on in the Medieval period.

KEYWORDS

Bronze and Iron Ages, charcoal analysis, colluvial deposits, landscape dynamics, prehistoric rural settlement, woodland composition

1 | INTRODUCTION

The origin and development of Holocene landscapes in the context of rural settlement and land use activities across the German central uplands are still difficult to determine due to limited research. For a long time, the climatically rough, higher areas (plateaus) of the uplands have been considered less favourable for settlement activities due to shorter vegetation periods and lower temperatures than the adjacent valleys (Denecke, 1992). Continuous occupation was considered unlikely during prehistoric times and presumably emerged no earlier than the Medieval period, as emphasized, for example, by Eberle et al. (2017, p. 155, own translation): '(…) Almost untouched during this phase [i.e., the Iron Age] were areas problematic for settlement, such as the rugged and impassable low mountain ranges'.

Archaeological research along the peripheral regions of the southern German central uplands focused on prehistoric monuments such as burial mounds (Mischka, 2007; Pankau, 2007; Sorcan, 2011) without yielding clear evidence of permanent rural settlement sites.

This focus gradually shifted when anthropogenic influence on the natural vegetation since the Neolithic and especially since the beginning of the Bronze Age became evident in some of the low mountain ranges of southern Germany, for example, the Taunus, the Rhön Mountains, and the Black Forest (Bringemeier & Stobbe, 2018; Henkner, Ahlrichs, Fischer, et al., 2018; Rösch, 2009, 2012; Rösch et al., 2015). In recent years, small-scale archaeological investigations and the re-evaluation of archival data have provided evidence of rural settlement activities during the Neolithic and Metal Ages in the western Allgäu region between the Swabian Jura and the Baar as well as the Black Forest (Ahlrichs et al., 2018; Höpfer et al., 2019, 2020; Miera et al., 2019). Still, large-scale archaeological excavations largely focused on fortified hilltop settlements at the margins of the upland plateaus that are commonly understood as seats of social elites or places with special functions (Abels, 1980, 2012; Krause, 2014; Krausse, 2008; Sandner, 2005), or as control of transportation routes (Gassmann et al., 2006). Likewise, a systematic investigation of geoarchaeological evidence of prehistoric land use has so far predominantly been performed in the vicinity of these prominent hilltop settlements or so-called 'princely sites' (Fürstenberg: Henkner et al., 2017; Henkner, Ahlrichs, Downey, et al., 2018; Scherer et al., 2021; Ipf: Mailänder et al., 2010; Schlossberg: Nelle & Schmidgall, 2003; Poschlod & Baumann, 2010; Heuneburg: Hansen et al., 2015, 2017; Rösch & Fischer, 2016). In other cases, land use indicators were geoarchaeologically detected without any relation to specific archaeological sites, be it rural or urban (Ahlrichs et al., 2018; Henkner, Ahlrichs, Fischer, et al., 2018).

Another reason to question previously held conceptions about the settlement history of the northern Franconian uplands, where our study area is located, is new evidence from Neolithic settlements (Burgdorf, 2017; Dürr et al., 2004; Fuchs et al., 2008, 2011; Mischka et al., 2015; Müller et al., 2009; Seregély, 2008; Seregély et al., 2019) and burial and ritual sites, many of which were still in use during the Metal Ages (Berger, 1984; Falkenstein, 2012; Seregély, 2012a, 2012b, 2012c; Seregély et al., 2015).

Rural settlement and land use activities during the 2nd and 1st millennium B.C.E. can therefore strongly be suspected in the extended surroundings of these burial and ritual sites, even though water availability has always been a limiting factor for human occupation on the uplands' plateaus (Gunzelmann, 1995). Thus, our project aimed to find evidence of Bronze and Iron Age rural settlement and related land use activities in the vicinity of burial and ritual sites on the plateaus. Fieldwork was complemented by an intensive dating programme using optically stimulated luminescence (OSL) and radiocarbon (^{14}C) dating to determine the temporal characteristics of the sediment dynamics within the study area. The resulting 29 OSL and 70 ^{14}C ages form the basis of our high-resolution chronology. We assigned our data to cultural periods or subperiods, and to their respective time spans in reference to common (pre-)historic chronologies of southern Germany (Table 1).

In the course of our multiannual research project, we systematically combined archaeological and geoarchaeological approaches. For reconstructing the prehistoric human–environmental interactions in regions without any peat bogs or lacustrine sediments as suitable environmental archives, colluvial deposits served as valuable site-specific evidence of past human activities and subsequent soil erosion (Fuchs et al., 2011; Henkner et al., 2017; Henkner, Ahlrichs, Downey, et al., 2018; Henkner, Ahlrichs, Fischer, et al., 2018; Kühn et al., 2017; Leopold & Völkel, 2007). This approach is based on the notion that periods of geomorphodynamic activity lead to a loss of vegetation (Rohdenburg, 1970). This loss can be caused by human activities, triggering soil erosion and colluvial sedimentation in the vicinity of permanent rural settlement sites. In addition, palaeoecological analysis of charcoal derived from archaeological features (onsite) and colluvial deposits (offsite) can provide essential information on the local fire and vegetational history (Baumann, 2006; Larsen et al., 2016; Robin & Nelle, 2014; Scherer et al., 2021).

2 | STUDY AREA

The study area is located in the northern Franconian Jura, an upland region in northern Bavaria, between the modern cities of Bamberg and Bayreuth (Figure 1). It is drained by the Weismain river, a tributary of the Main river, that builds a fluvial catchment of about 125 km^2. The lithology of the study area consists of Jurassic dolomite, limestone, and sandstone. The relief is characterized by narrow valleys deeply incised into the undulating plateaus, which is typical for a karstic landscape.

Cambisols and Luvisols as dominant soil types of the region (IUSS Working Group WRB, 2015) developed from Pleistocene cover beds and comprise a significant loess component. Climatically, the region today shows typical values for northern Bavaria, with a mean annual precipitation of about 800 mm and a mean annual temperature of 7.5°C for the city of Weismain (Deutscher Wetterdienst, 2021).

For this study, four locations were investigated on the plateaus (Figure 1), all of them with their specific geomorphology, composed of spurs, gentle slopes with partly terrace-like steps, and depressions at footslope positions. This individual geomorphology and spatial patterns of soil erosion and accumulation also determine the soilscapes of the study area.

3 | MATERIALS AND METHODS

3.1 | Archaeological fieldwork

To determine the settlement sites worthy of excavation, a surface survey was undertaken starting from known sites and site location analysis using GIS (details in Kothieringer et al., 2018). Thus, concentrations of archaeological finds could be identified as a

TABLE 1 Chronology of the cultural periods in the study area

Cultural period	Subperiod	Further division of subperiod	Approximate age
Modern Era			>1500 cal. C.E.
Medieval period	Late		1300–1500 cal. C.E.
	High		1000–1300 cal. C.E.
	Early		480–1000 cal. C.E.
Migration period			350–480 cal. C.E.
Roman period			0–350 cal. C.E.
Iron Age	Late	Middle and Late La Tène	250–0 cal. B.C.E.
	Middle	Late Hallstatt and Early La Tène	650–250 cal. B.C.E.
	Early	Early Hallstatt	800–650 cal. B.C.E.
Bronze Age	Late	Younger Urnfield	950–800 cal. B.C.E.
		Middle Urnfield	1100–950 cal. B.C.E.
		Older Urnfield	1200–1100 cal. B.C.E.
		Early Urnfield	1270–1200 cal. B.C.E.
	Middle		1550–1270 cal. B.C.E.
	Early		2200–1550 cal. B.C.E.
Neolithic period	End		2800–2200 cal. B.C.E.
	Late		3500–2800 cal. B.C.E.
	Younger		4400–3500 cal. B.C.E.
	Middle		5000–4400 cal. B.C.E.
	Early		5500–5000 cal. B.C.E.
Mesolithic period			9600–5500 cal. B.C.E.

Note: Finer chronologies of the Neolithic period after Lüning (1996), of the Bronze Age after David (2006), of the Urnfield period after Hennig (2006) and Trachsel (2004), of the Iron Age after Trachsel (2004) and Uenze (2006), of the Roman period, and the Migration period after Haberstroh (2000).

possible indicator of subsurface archaeological features. We then performed a magnetic survey of all potential settlement sites using a Bartington Grad601-2 fluxgate gradiometer. A combined review of magnetic anomalies and find concentrations in GIS indicated potential archaeological subsurface features. Some of these were tested with a handheld soil auger 'Edelman' before the excavation to exclude any geologically caused magnetic anomalies. Overall, a total of 23 unambiguous archaeological sites as well as six additional areas with onsite colluvial deposits were discovered within the four study locations. Six to ten small test trenches with 1–1.3 m width and 1–6 m length were then dug at each potential settlement site. Approximately 10 l of sediment was taken from each feature to recover macro residues through wet-sieving.

3.2 | Pedological fieldwork and analytics

Following GIS-based site location analysis, offsite soil sampling in the vicinity of potential settlement features or burial mounds was conducted mainly in depressions on spurs or on slopes with terrace-like steps, where colluvial deposits might have accumulated. Soil augering was also performed at three inner-plateau depressions (Figure 1, white circular symbols with black dots). Here, the deposits did not contain charcoal remains or other features related to past human activities. Overall, about 220 locations were investigated by soil augering and then by digging soil pits at locations with a representative soil stratigraphy. Sampling of thicker deposits was performed at regular intervals. All soil sampling coordinates were mapped with a differential GPS of 1–2 cm accuracy (Leica GNSS, GS 14). Pedological descriptions followed German guidelines of the Ad-hoc-AG Boden der Staatlichen Geologischen Dienste und der Bundesanstalt für Geowissenschaften und Rohstoffe (2005) and were then transferred to international nomenclature (IUSS Working Group WRB, 2015). The designation of the colluvial deposits as 'M horizons' (from Latin 'migrare', to migrate) was retained from the German guidelines. In each stratigraphy, the lowermost (and oldest) deposit was named 'M1'. The Munsell Color Company (2009) soil-colour chart was used to identify the colour of the soil horizons and layers.

Standard pedological analytics included the grain size analyses using the pipette method according to Köhn (1929), the measurement of pH in $CaCl_2$ (Amelung et al., 2018), the determination of

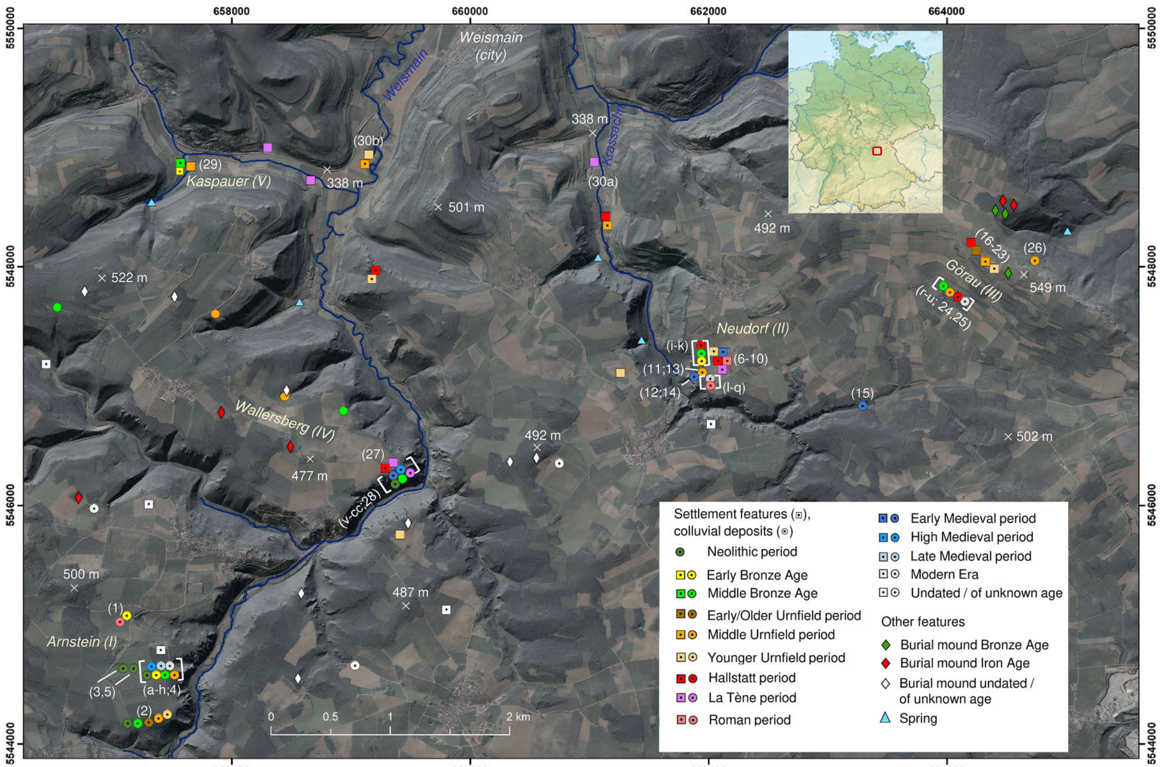


FIGURE 1 Archaeologically and geoarchaeologically investigated plateaus (I Arnstein, II Neudorf, III Görau, IV Wallersberg), and valley settlement Kaspauer (V) under current agricultural use and forestry in our study area in the northern Franconian uplands. Map frame with UTM coordinates. Square symbols with black dots represent rural settlement features dated by ^{14}C; circular symbols with black dots stand for ^{14}C and optically stimulated luminescence dated colluvial deposits. For numbers, see Table 2; for letters, see Table 3. Note that sediments of Pleistocene or Early Holocene age are not mentioned in this figure, as they were not interpreted as being of anthropogenic origin. For their ages, see text and Table 3. Previously published (geo-)archaeological features are marked with plain square and circular symbols (Kothieringer et al., 2018). *Sources*: Digital elevation model (DEM, 1 m), ortophoto (20 cm): Bayerische Vermessungsverwaltung. Map of Germany: https://commons.wikimedia.org/ (CC BY-SA 3.0). Graphics: K. Kothieringer.

calcium carbonate ($CaCO_3$) according to Scheibler (Amelung et al., 2018), and the measurement of total organic carbon (TOC) according to Riehm and Ulrich (1954).

3.3 | Archaeozoological analysis

Bones were classified (by Chr. Baumann, University of Tübingen) by species of animal where properly preserved. However, the decalcification of the soil has led to the complete destruction of the bone substance in most places.

3.4 | Palaeoecological analysis

From the on- and offsite samples recovered by wet-sieving, botanical macroremains including charcoal residues were analysed with regard to their type. Charcoal fragments larger than 0.63 mm were identified using the Microscopic Wood Anatomy Atlas by Schweingruber (1990). To facilitate identification, fresh breaks were created in the transversal, tangential, and radial orientation. A stereo magnifying glass (Zeiss Stemi 508) and a microscope (Zeiss Axio Scope.A1) with a maximum magnification of x500 were used for classification. A total of 674 onsite pieces from features and colluvial deposits were analysed, of which 32 could be identified as residues of grains, 17 as other seed residues, and 625 as charcoal residues. A total of 294 pieces (including 293 charcoal residues and one Galium seed) were analysed from the offsite colluvial material. All in all, of the 918 charcoal fragments analysed, 847 could be assigned to a specific taxon.

3.5 | Micromorphological analysis

Thin-section analysis was performed to characterize the genesis of the soil stratigraphy in the Arnstein depression (Section 4.1.2). Two undisturbed samples were taken as Kubiena boxes in a soil pit. The samples were air-dried, impregnated with polyester resin, and subdivided into two thin sections each (Beckmann Laboratory). They were identified using a microscope (Olympus BX 51) under 600 magnification with plane-polarized (PPL) and crossed-polarized light (XPL). The description mainly follows the terminology of Stoops (2021).

3.6 | Radiocarbon dating

When present, residual cereals or shorter-lived tree species were preferred to longer-lived species such as oak because of the possible effect of heartwood for ^{14}C dating. For age determination of the samples listed in Table 2, radiocarbon AMS dating was carried out by the Isotoptech Zrt. AMS laboratory (Debrecen, Hungary; lab code 'DeA'). For combustion of charred remains and CO_2 purification, the laboratory uses a self-developed in-line combustion and CO_2 purification line based on a system developed at the University of Arizona (Molnár, Janovics, et al., 2013). Two-stage heating (400°C, 'L-low' and 800°C, 'H-high' fraction) ensured precise temperature-stabilized gradual fractional oxidation. For testing organic sample preparation procedures, the laboratory used international ^{14}C reference materials with known ^{14}C activity (IAEA C9 wood). AMS graphite targets were prepared using a sealed tube graphitization method at HEKAL (Rinyu et al., 2013).

All ^{14}C measurements were made on the graphitized samples using a compact radiocarbon AMS system (Environ MICADAS; Molnár, Rinyu, et al., 2013). NIST SRM 4990C standards and borehole CO_2 blanks were used for normalization of the AMS measurements. The results were corrected for decay of the standard and the effect of $\delta^{13}C$ isotopic fractionation (Synal et al., 2007). For data reduction of the measured values, 'BATS' software was used (Wacker et al., 2010). More details on the protocols used to prepare single samples are given in the supplementary file. ^{14}C ages were calibrated using OxCal 4.4.4 based on IntCal20 (Reimer et al., 2020).

3.7 | OSL dating

OSL samples were collected during daytime periods using opaque steel cylinders of different diameters. Dose rate samples were taken within a radius of 30 cm around the OSL sample to account for inhomogeneous gamma dose rates in the surrounding sediment. In case of multiple sampling per layer, dose rate samples were collected as close as possible at the respective cylinder.

To determine the equivalent dose (D_e), the sediment was wet-sieved to separate the grain size fractions, followed by treatment with 10% HCl and 10% H_2O_2 to remove any carbonates and organics. To receive the quartz fraction, lithium-heteropolytungstate (2.63 and 2.69 g/cm^3) was used for density separations and 40% hydrofluoric acid was used to remove the α-irradiated outer layer of the grains and to eliminate remaining feldspar contamination. All measurements were carried out on Freiberg Instrument Lexsyg readers at the University of Giessen using green light stimulation (525 ± 25 nm) (Lomax et al., 2014). D_e of the coarse grain quartz fraction (90-200 µm) was measured using a single-aliquot regenerative-dose (SAR) protocol (Murray & Wintle, 2000, 2003). The shine-down curves were measured for 50 s at elevated temperatures (125°C) after preheating at 180°C (10 s) and a cut-heat at 160°C for the natural and regenerated signals, except for samples GI697–GI706, for which preheating at 200°C and a cut-heat at 180°C were chosen. The preheat and cut-heat temperatures were chosen after a preheat-plateau test (PHT) and a combined preheat-dose recovery test (DRT). For the DRT, the samples were bleached in the Lexsyg reader using the green LEDs and irradiated with a known β-dose close to the natural dose, followed by D_e determinations using the SAR protocol. For the PHT, burial doses were also measured using the SAR protocol. Both tests were conducted at six different preheat temperatures (180–280°C). For the determination of D_e, the integral of the first 0.5 s of the quartz shine-down curves was used, after subtracting a background of 40 to 50 s from the signal. All D_e measurements were carried out on small multiple grain aliquots (2 mm) containing ca. 120 grains per aliquot, of which, in general, 30–40 aliquots per sample were measured. We expected D_e distributions for our samples to be overdispersed due to insufficiently bleaching, mixing of grains with different depositional ages, and inclusion of grains that were surface-exposed after stabilization. Therefore, the Inter-Quartile Range (IGR) was calculated and aliquots beyond the lower and upper bounds were treated as outliers and were removed from the data set. For the calculation of D_e, the unweighted median of the cleaned data set was used.

To determine the radionuclide concentrations, a combination of thick source α-counting (for U and Th) and ICP-OES (for K) was applied to samples taken at Neudorf, Görau, and Wallersberg. Radionuclide concentrations of samples GI 697–GI 706 (Arnstein) were determined through a combination of α- and β-counting in a µDose system (Kolb et al., 2022; Tudyka et al., 2020). For further information, see Supporting Information: Table S1.

4 | RESULTS

4.1 | Arnstein plateau (I)

4.1.1 | Archaeological results

In contrast to the other studied locations, the Arnstein plateau had been previously surveyed by volunteers. All detected sites yielded very few finds or single objects such as highly fragmented pottery sherds or chert flakes as possible relicts of Mesolithic camps or Neolithic settlements. Finds from the Urnfield and Late Hallstatt/Early La Tène periods are known from the so-called 'Heidenknock', a mountain spur site with ramparts and ditches of unknown age that were probably further extended in the Early Medieval period (Ostermeier, 2012). Typical settlement ceramics of the Late Hallstatt/Early La Tène period were found on another mountain spur east of the modern village of Arnstein. Single bronze artefacts from the plateau include a tympanum-shaped fibula from the Late Hallstatt period as well as a club-headed pin, a spearhead, and a sickle from the Late Bronze Age. Three mounds had been excavated in the late 19th century (Seyler, 1887): two of them contained bronze objects of the Hallstatt period, and the third of the mounds excavated contained bronze artefacts of the Middle Bronze Age.

TABLE 2 ^{14}C dated material from archaeological features and colluvial deposits

Name of plateau	No. of arch. feature/ coring location	Type of archaeological feature, or soil stratigraphy incl. soil horizon; depth of sampling (m)	Sample type and wood type	Lab code (DeA-)	^{14}C Age (B.P.[†] ± 1σ)	Calibrated calendar age (cal B.C.E./C.E. ± 2σ)
I Arnstein	1a	Colluvial layer	c (*Fraxinus*)	16177	3576 ± 18	2016–1831 cal. B.C.E.
	1b	Colluvial layer	c (*Fagus*)	16175	1701 ± 16	260–411 cal. C.E.
	2a	Colluvial layer	c (*Acer*)	15682	5246 ± 23	4225–3979 cal. B.C.E.
	2b	Colluvial layer	cc (*Trit.monoc.*)	13506	3009 ± 29	1385–1127 cal. B.C.E.
	2c	Colluvial layer	c (*Fagus*)	15680	2786 ± 20	1007–847 cal. B.C.E.
	3a	Ap-M3-M2-**M1-2Bw;** 2.15	c (*Quercus*)	14182	3909 ± 27	2469–2298 cal. B.C.E.
	3b	Ap-M3-**M2**-M1-2Bw; 1.35	c (*Quercus*)	15553	3628 ± 31	2129–1895 cal. B.C.E.
	3c	Ap-**M3**-M2-M1-2Bw; 0.80	c (*Carpinus*)	14180	368 ± 35	1450–1635 cal. C.E.
	4a	Ap-M4-M3-M2-**M1-2Bw;** 3.30	c (*Quercus*)	14520	3891 ± 33	2469–2285 cal. B.C.E.
	4b	Ap-M4-M3-**M2**-M1-2Bw; 2.70	c (*Quercus*)	16603	3688 ± 20	2142–1981 cal. B.C.E.
	4c	Ap-M4-M3-**M2**-M1-2Bw; 2.10	c (*Quercus*)	15522	3077 ± 30	1421–1261 cal. B.C.E.
	4d	Ap-**M4-M3**-M2-M1-2Bw; 1.50	c (*Carpinus*)	15557	1709 ± 22	256–412 cal. C.E.
	4e	Ap-**M4**-M3-M2-M1-2Bw; 0.60	c (*Fraxinus*)	16600	230 ± 17	1642–1800 cal. C.E.
	5a	Ap-M3-M2-**M1-2Bw**; 1.30	c (*Quercus*)	14521	3806 ± 42	2454–2063 cal. B.C.E.
	5b	Ap-M3-**M2**-M1-2Bw; 1.00	c (*Quercus*)	15555	3491 ± 32	1897–1696 cal. B.C.E.
II Neudorf	6a	Pit	c (*Carpinus*)	13564	2689 ± 27	900–804 cal. B.C.E.
	6b	Pit	c (*Betula*)	16098	2452 ± 23	751–415 cal. B.C.E.
	6c	Pit	f (*Carpinus*)	13503	1709 ± 26	254–414 cal. C.E.
	7	Small ditch	c (*Carpinus*)	16097	1316 ± 22	656–775 cal. C.E.
	8a	Colluvial layer	c (*Fraxinus*)	16656	5054 ± 26	3951–3785 cal. B.C.E.
	8b	Colluvial layer	c (*Fagus*)	16658	2834 ± 24	1102–911 cal. B.C.E.
	9a	Posthole	cc (*Trit.dic.*)	14412	2669 ± 24	899–795 cal. B.C.E.
	9b	Posthole	cc (*Trit.dic.*)	14413	2478 ± 23	769–514 cal. B.C.E.
	9c	Posthole	c (*Corylus*)	16099	2333 ± 26	471–266 cal. B.C.E.
	10a	Pit	c (*Fagus*)	16185	1825 ± 17	133–315 cal. C.E.
	10b	Pit	c (*Fagus*)	16170	1802 ± 19	214–325 cal. C.E.
	11a	Ah-M2-**M1**-2Bw; 0.83	c (*Quercus*)	16597	2789 ± 40	1046–830 cal. B.C.E.

(Continues)

TABLE 2 (Continued)

Name of plateau	No. of arch. feature/ coring location	Type of archaeological feature, or soil stratigraphy incl. soil horizon; depth of sampling (m)	Sample type and wood type	Lab code (DeA-)	^{14}C Age (B.P.[†] ± 1σ)	Calibrated calendar age (cal B.C.E./C.E. ± 2σ)
	11b	Ah-**M2**-M1-2Bw; 0.45	c (*Quercus*)	16884	2926 ± 39	1258–1009 cal. B.C.E.
	11c	Ah-**M2**-M1-2Bw; 0.27	c (*Pinus*)	11291	124 ± 20	1683–1936 cal. C.E.
	12a	Ah-M3-M2-**M1**-2Bw; 2.20	c (*Fagus*)	11293	1209 ± 22	710–887 cal. C.E.
	12b	Ah-M3-**M2**-M1-2Bw; 1.25	c (*Abies*)	11292	581 ± 21	1309–1410 cal. C.E.
	12c	Ah-**M3**-M2-M1-2Bw; 0.35	c (*Fagus*)	9920	130 ± 27	1675–1942 cal. C.E.
	13a	Ah-M3-M2-**M1**-2Bw-3Bw; 1.55	c (*Quercus*)	16672	2690 ± 39	915–797 cal. B.C.E.
	13b	Ah-M3-**M2**-M1-2Bw-3Bw; 1.45	c (*Quercus*)	12142	2802 ± 28	1045–845 cal. B.C.E.
	13c	Ah-M3-**M2**-M1-2Bw-3Bw; 1.35	c (*Quercus*)	16671	2860 ± 37	1191–916 cal. B.C.E.
	13d	Ah-M3-**M2**-M1-2Bw-3Bw; 1.25	c (*Carpinus*)	16882	2900 ± 38	1216–940 cal. B.C.E.
	13e	Ah-**M3**-M2-M1-2Bw-3Bw; 0.34	c (*Populus*)	14522	242 ± 20	1636–1800 cal. C.E.
	14	Ah-**M1**-2Bw-3Bw; 0.58	c (*Fagus*)	11294	1196 ± 22	773–888 cal. C.E.
	15	Ah-**M1**-2Bw; 0.90	c (*Fagus*)	16880	1315 ± 37	650–775 cal. C.E.
III Görau	16a[‡]	Depression + cultural layer	cc (*Hord.vulg.*)	10873	2992 ± 27	1376–1123 cal. B.C.E.
	16b	Depression + cultural layer	c (*Betula*)	15566	2786 ± 31	1011–835 cal. B.C.E.
	16c	Depression + cultural layer	c (*Corylus*)	15567	1567 ± 23	431–562 cal. C.E.
	16d	Depression + cultural layer	c (*Maloideae*)	15568	1038 ± 22	979–1034 cal. C.E.
	17[‡]	Posthole	c (*Fagus*)	11556	2446 ± 22	750–412 cal. B.C.E.
	18	Posthole	cc (*Hord.vulg.*)	13504	2951 ± 29	1260–1052 cal. B.C.E.
	19	Posthole	cc (*Trit.dic.*)	13505	2725 ± 29	921–811 cal. B.C.E.
	20a	Posthole	c (*Fagus*)	16640	3103 ± 24	1430–1291 cal. B.C.E.
	20b	Posthole	c (*Maloideae*)	16638	2726 ± 26	919–813 cal. B.C.E.
	21	Posthole	cc (*Trit.dic.*)	16444	2921 ± 24	1212–1019 cal. B.C.E.
	22a	Pit	cc (*Trit.dic.*)	16642	2900 ± 27	1204–1007 cal. B.C.E.
	22b	Pit	cc (*Trit.dic.*)	16596	2850 ± 25	1110–927 cal. B.C.E.
	23a	Posthole	cc (*Trit.dic.*)	16654	2739 ± 24	928–819 cal. B.C.E.
	23b	Posthole	cc (*Trit.dic.*)	16646	2626 ± 23	817–780 cal. B.C.E.
	24a	Ap-M3-M2-**M1-2Bw**; 1.05	c (*Fagus*)	15549	3512 ± 32	1928–1745 cal. B.C.E.

TABLE 2 (Continued)

Name of plateau	No. of arch. feature/ coring location	Type of archaeological feature, or soil stratigraphy incl. soil horizon; depth of sampling (m)	Sample type and wood type	Lab code (DeA-)	^{14}C Age (B.P.[†] ± 1σ)	Calibrated calendar age (cal B.C.E./C.E. ± 2σ)
	24b	Ap-M3-M2-**M1**-2Bw; 0.90	c (*Fagus*)	16678	3347 ± 39	1740–1518 cal. B.C.E.
	24c	Ap-M3-**M2**-M1-2Bw; 0.80	c (*Quercus*)	16672	2891 ± 41	1214–933 cal. B.C.E.
	24d	Ap-M3-**M2**-M1-2Bw; 0.77	mr (*Galium*)	16795	2424 ± 49	755–400 cal. B.C.E.
	24e	Ap-M3-**M2**-M1-2Bw; 0.74	c (*indet*)	15521	2313 ± 28	412–232 cal. B.C.E.
	24f	Ap-**M3**-M2-M1-2Bw; 0.40	c (*conif.wood*)	16676	207 ± 35	1639–mod. cal. C.E.
	25	Ap-M4-M3-M2-**M1**-2Bw; 0.95	c (*Maloideae*)	12919	3161 ± 23	1500–1400 cal. B.C.E.
	26a	Ah-M1-2Bg-**2Bdg**; 0.45	c (*Fagus*)	12917	2807 ± 22	1015–901 cal. B.C.E.
	26b	Ah-**M1-2Bg**-2Bdg; 0.20	c (*conif.wood*)	12914	65 ± 18	1696–1916 cal. C.E.
IV Wallersberg	27a	Pit	c (*Fagus*)	14419	2480 ± 22	769–516 cal. B.C.E.
	27b[‡]	Pit	c (*Fagus*)	12144	2347 ± 27	514-380 cal. B.C.E.
	28a	Ah-M5-fAh-M4-M3-M2-**M1-2Bw**; 1.40	c (*indet*)	16680	4594 ± 43	3516–3104 cal. B.C.E.
		Ah-M5-fAh-M4-M3-**M2**-M1-2Bw; 1.26				
	28b	Ah-M5-fAh-M4-**M3**-M2-M1-2Bw; 1.02	c (*Quercus*)	16679	3015 ± 40	1396–1125 cal. B.C.E.
		Ah-M5-fAh-M4-**M3**-M2-M1-2Bw; 0.95				
	28c	Ah-M5-**fAh**-M4-M3-M2-M1-2Bw; 0.45	c (*Populus*)	14176	957 ± 25	1029–1158 cal. C.E.
		Ah-M5-fAh-M4-M3-**M2**-M1-2Bw; 1.10				
	28d		c (*Prunus*)	16898	1046 ± 36	892–1117 cal. C.E.
	28e		c (*Maloideae*)	14173	606 ± 22	1302–1402 cal. C.E.
	28f[‡]		c (*Quercus*)	Poz-51352	3285 ± 30	1622–1498 cal. B.C.E.
V Kas-pauer	29a	Cultural layer in palaeoriver channel	bone	Poz-48465	3455 ± 35	1885–1641 cal. B.C.E.
	29b	Pit		16183		
			mr (*indet*)		3367 ± 18	1739–1565 cal. B.C.E.
Valley loca-tions	30a	Pit	cc (*Trit.dic.*)	10878	1836 ± 25	126–310 cal. C.E.
	30b	Posthole	c (*Fagus*)	15573	1694 ± 23	259–416 cal. C.E.

Note: Sample type: c, charcoal; cc, charred crop; mr, macroremain; f, fruit (charred); mg, micrographite.

[†] B.P. = radiocarbon years before 'present' (=C.E. 1950).

[‡] ^{14}C age already published in Kothieringer et al. (2018), age of no. 28 f from soil augering in close proximity to the soil pit presented in this paper.

Some sherds of the Urnfield culture had already been collected in the 1990s at the first site that we investigated (*Arns683*, no. 1, Figure 1). This site is located in a slight depression immediately adjacent to two dolines. These dolines are under nature protection and therefore could not be surveyed. Six of the excavation trenches revealed no traces of archaeological features. In four of them, a reddish-brown, clay-rich, and decalcified subsoil (*terra fusca)* was found below the plough horizon. In two trenches, we documented a homogeneous ochre, silty colluvial deposit with a thickness of about 0.75 m. The layer contained scattered charcoal and a single small prehistoric sherd. Two charcoal fragments (*Fraxinus* and *Fagus*) were selected for radiocarbon dating—the first fragment dates to the Early Bronze Age and the second fragment dates to the Late Roman period (nos. 1a–b, Table 2). Both trenches with the colluvial layer were dug across the centre of two larger magnetic anomalies. Thus, we interpret these anomalies as completely filled smaller dolines.

The second investigated site (*Gros128*, no. 2, Figure 1) also did not provide any evidence of *in situ* settlement features. In four of the six excavated trenches, a greyish-brown to reddish colluvial deposit overlying the *terra fusca* (Figure 2a) was found. The layer contained some prehistoric sherds, fragments of querns and grinding stones, charcoal, and macroremains. The sherds were extremely poorly preserved–the edges of the fragments were mostly abraded and the original surfaces flaked off. In some cases, however, there were still some larger, matching fragments, so that a relocation of the finds over a great distance is unlikely. Only one sherd can be classified typochronologically in the Late Bronze Age. The thickness of the colluvium fluctuates between 0.1 and 0.25 m and the three ^{14}C dates (*Acer*, *Triticum monococcum*, and *Fagus*) again suggest mixing of the sediment with material from several epochs: the Younger Neolithic, the Middle Bronze Age to the Early Urnfield period, and the Middle to Younger Urnfield period (nos. 2a–c, Table 2). The finds in the colluvium apparently come from a multi-period settlement further up the slope, north of the excavation area. As this area was also prospected, but no finds were identified, it is assumed that the settlement(s) have been completely destroyed by erosion.

4.1.2 | Georchaeological results

Soil augering was performed at a nearby settlement site of unknown age (white square with a black dot in the southern part of the Arnstein plateau, Figure 1) and in the vicinity of our archaeological investigations (nos. 1–2, Figure 1). There, a prominent sink acts as a colluvial sediment trap that records past human activities around the former settlements.

The stratigraphy with the largest sequence of colluvial deposits at the deepest point of the sink is presented in more detail in the following (Figure 3a). Samples for OSL dating and micromorphological analysis were taken from an undisturbed soil pit that was dug at a distance of a few metres from the augering location. The stratigraphy obtained by augering could be correlated very well with the one from the pit, despite varying absolute depths and relative thicknesses of the single horizons. All OSL ages are in stratigraphic order, and all ^{14}C ages from the augering profile are in accordance with the OSL ages, except for no. 4d (Table 2).

At about 3.3 m depth, a sterile, yellowish-brown layer with a texture of medium silty clay was identified. The OSL sample shows an age of 24.45 ± 2.30 ka (no. a, Table 3). Thus, this layer is interpreted as a Pleistocene slope deposit, that is, a periglacial cover bed or reworked *terra fusca* (Bw horizon). Reworking of Pleistocene loess is reflected by the high content of silt of about 65% (Figure 3a).

The layer above the slope deposit represents the chronologically oldest colluvial deposit M1 of almost 1 m thickness. Two OSL ages, which were sampled in the upper and lower parts of M1 (nos. b–c, Table 3), show within errors the same age and thus ascribe M1 to one phase of human-induced soil erosion during the Early to Middle Bronze Age. Charcoal of the type oak (*Quercus*) collected at 3.3 m was dated to the End Neolithic Age (no. 4a, Table 2). The deposit was charcoal-rich, especially between 2.7 m and 2.4 m, with oak charcoal dating to the Early Bronze Age (no. 4b). Taking the heartwood effect of oak into account, both ^{14}C ages may be from the same time.

The 0.3 m thick colluvial deposit M2 shows human-induced soil erosion and the burning of oak in the Middle to Late Bronze Age (no. d, Table 3; no. 4c, Table 2). Thin-section analysis from sampling this M horizon at 2.35 m to 2.43 m depth (Figure 4a) evidenced the presence of burnt roots and a high amount of microscopic plantcoal (Figure 4b), yielding a high TOC value of almost 1% (Figure 3a).

We first thought of the very dark horizon M3 as a buried humic former surface. However, thin-section analysis from sampling M3 at 1.68 to 1.76 m depth (Figure 4c) revealed typical characteristics of colluvial relocation of soil material. This is indicated by a ‘dusty’ soil matrix due to the incorporation of humic material into the ground mass during soil erosion and an abundant microscopic plantcoal (Figure 4d). The presence of dusty clay and silt coatings (Figure 4d) can be ascribed to the mobilization of soil components by water, as long as the soil surface is bare (Jongerius, 1970). This stands in contrast to the finding of abundant multilaminated limpid clay coatings (Figure 4d) that are also present in the same soil unit. Their formation was most likely caused by the dispersion of clay colloids during leaching of the soil under a continuous vegetation cover (Buurman et al., 1998; Kühn et al., 2018). We interpret the formation of intact limpid clay coatings as a post-sedimentary process under geomorphodynamic stability, leading to the transformation of the deposit into an argic horizon through clay illuviation. Limpid clay coatings frequently occur in M2 as well; thus, we assume that they are present throughout the whole soil profile.

The formation of M3 dates to the transition of the Late Bronze Age to the Middle Iron Age (no. e, Table 3). At 1.1%, this horizon records the highest TOC content of all M horizons (Figure 3a).

Charcoal of the type hornbeam (*Carpinus*), collected at the transition of M3 to M4 at 1.5 m soil depth, dates to the Late Roman period (no. 4d, Table 2). This age overestimates the OSL age recorded at 1.4 m depth (no. f, Table 3), which could be explained by the incorporation of old organic material into the sedimentation cycle. Charcoal sampled at about 0.6 m soil depth evidences fire activities and burning of ash (*Fraxinus*) in the Early Modern Era (no. 4e, Table 2). OSL dating of M4 provides a high resolution of human-induced soil erosion by recording three phases from the High Medieval period to the Modern Era (nos. f–h, Table 3).

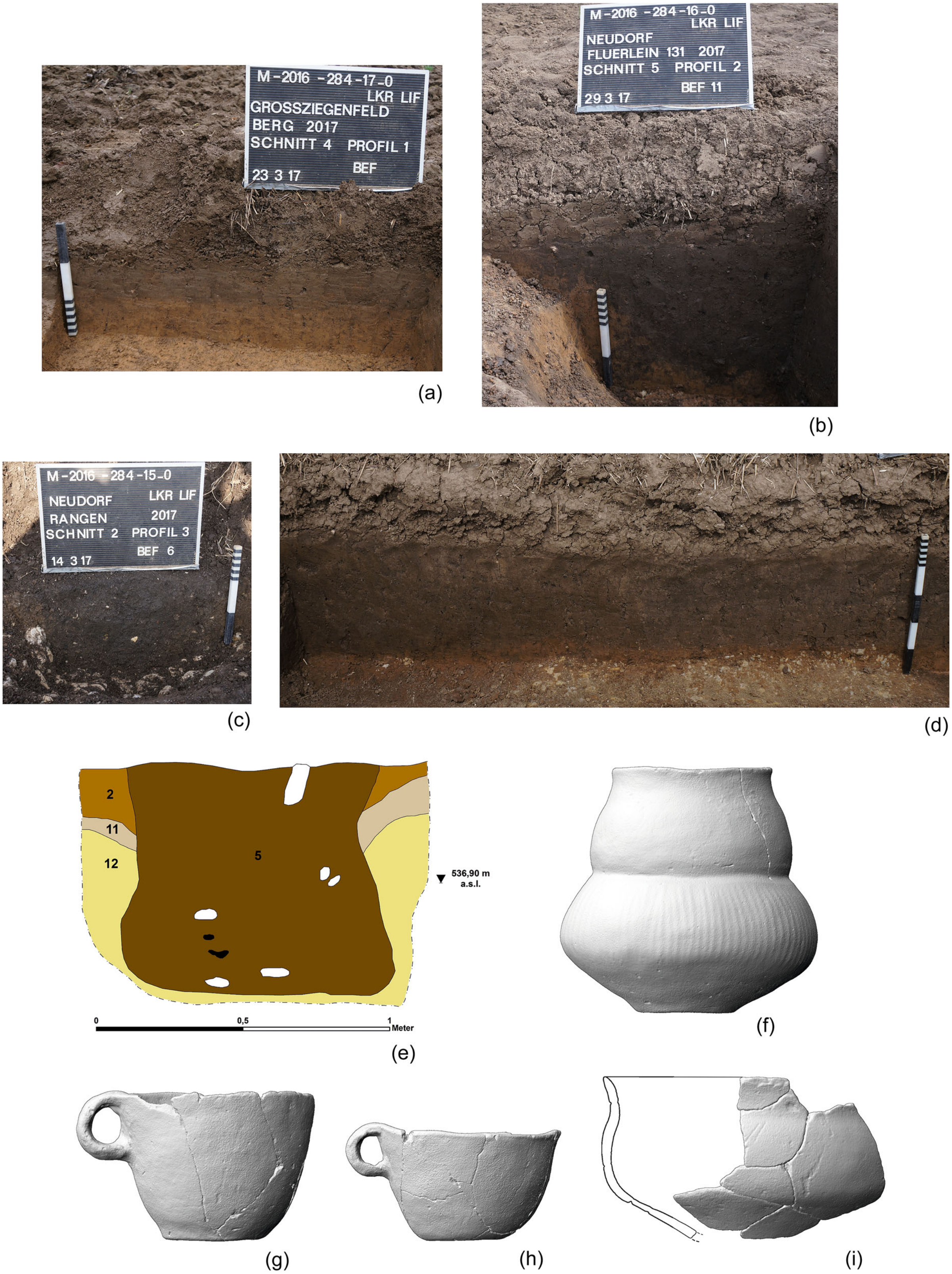
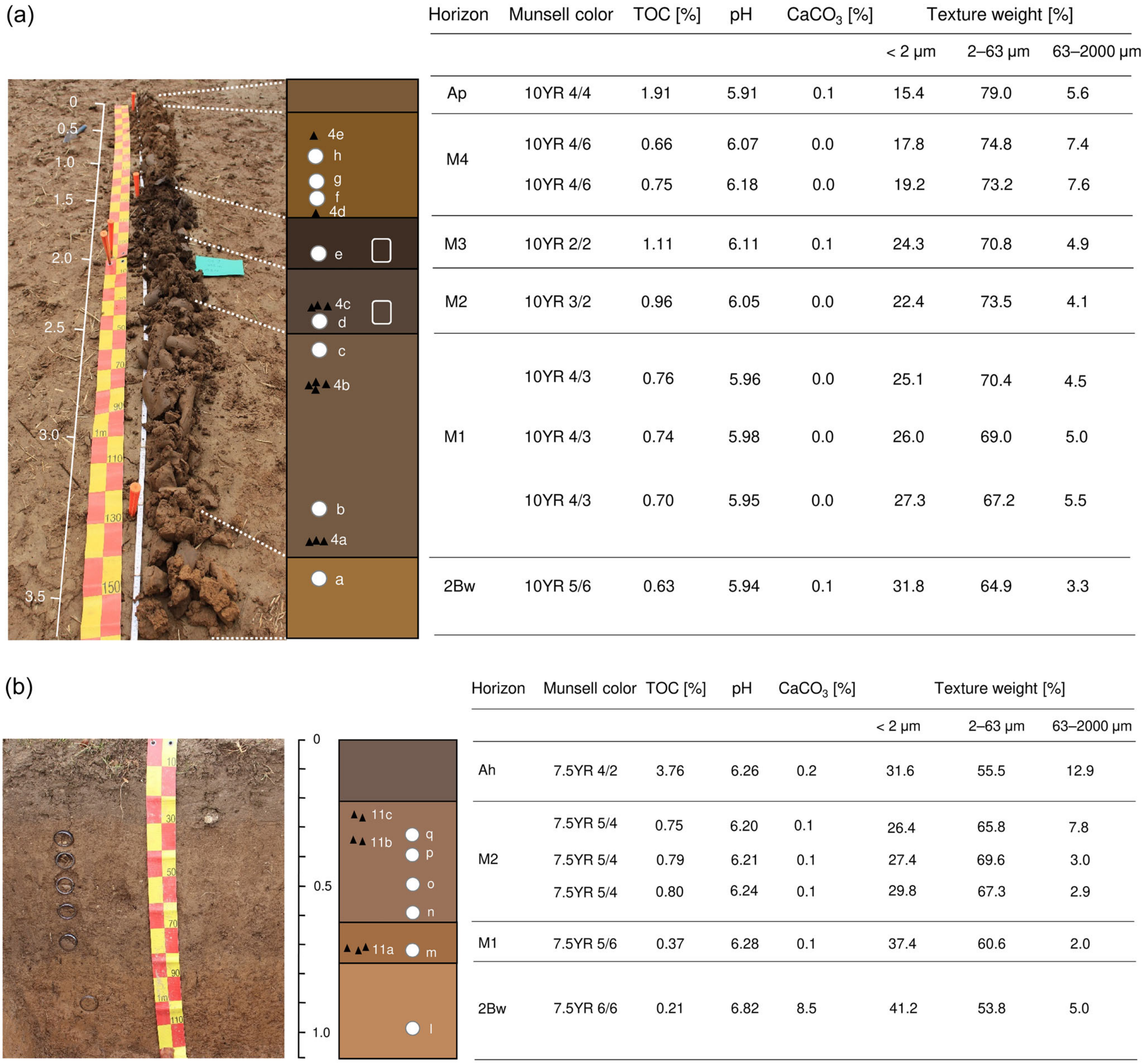


FIGURE 2 Archaeological features and finds. (a) Arnstein plateau (*Gros128*), greyish-brown colluvial deposit above *terra fusca*. (b) Neudorf plateau (*Neud131*), settlement pit. (c) Görau ridge (*Neud1500*), posthole. (d) Görau ridge (*Neud1500*), colluvial deposit. (e) Görau ridge (*Neud1497*), Late Bronze Age storage pit. Feature 2 (greyish-brown silty loam) and feature 11 (light-brown silty loam) are sediments that accumulated after the pit had been dug into the soil—the upper part of the pit probably had been lined with timber. Feature 5 is a dark brown, silty loamy deposit rich in finds that filled the pit after losing its storage function. Feature 12 is the yellowish, clay-rich *terra fusca*. (f)–(i) Görau ridge (*Neud1497*). Ceramic vessels from the Late Bronze Age storage pit (scale 1:3). All photos and graphics: T. Seregély.



(a)

Horizon	Munsell color	TOC [%]	pH	$CaCO_3$ [%]	Texture weight [%]		
					< 2 µm	2–63 µm	63–2000 µm
Ap	10YR 4/4	1.91	5.91	0.1	15.4	79.0	5.6
M4	10YR 4/6	0.66	6.07	0.0	17.8	74.8	7.4
	10YR 4/6	0.75	6.18	0.0	19.2	73.2	7.6
M3	10YR 2/2	1.11	6.11	0.1	24.3	70.8	4.9
M2	10YR 3/2	0.96	6.05	0.0	22.4	73.5	4.1
M1	10YR 4/3	0.76	5.96	0.0	25.1	70.4	4.5
	10YR 4/3	0.74	5.98	0.0	26.0	69.0	5.0
	10YR 4/3	0.70	5.95	0.0	27.3	67.2	5.5
2Bw	10YR 5/6	0.63	5.94	0.1	31.8	64.9	3.3

(b)

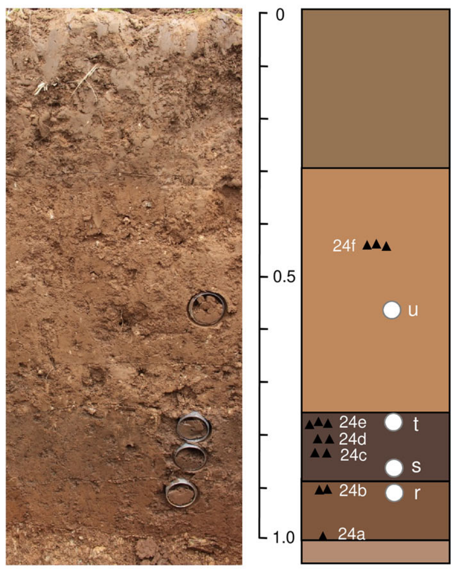
Horizon	Munsell color	TOC [%]	pH	$CaCO_3$ [%]	Texture weight [%]		
					< 2 µm	2–63 µm	63–2000 µm
Ah	7.5YR 4/2	3.76	6.26	0.2	31.6	55.5	12.9
M2	7.5YR 5/4	0.75	6.20	0.1	26.4	65.8	7.8
	7.5YR 5/4	0.79	6.21	0.1	27.4	69.6	3.0
	7.5YR 5/4	0.80	6.24	0.1	29.8	67.3	2.9
M1	7.5YR 5/6	0.37	6.28	0.1	37.4	60.6	2.0
2Bw	7.5YR 6/6	0.21	6.82	8.5	41.2	53.8	5.0

FIGURE 3 (a)–(d) Stratigraphy, position of dated charcoal (triangles/numbers, Table 2), optically stimulated luminescence samples (dots/letters, Table 3), micromorphological samples (rectangles), and standard soil parameters of soil profiles that were investigated in representative sediment traps at the four plateaus. a: Arnstein, b: Neudorf, c: Görau, d: Wallersberg. For Arnstein, horizons from augering could be correlated with those from the undisturbed soil pit despite varying absolute depths and relative thicknesses of the single horizons. Lines in redrawings mark boundaries of soil horizons. n.a.: no data available. All photos and graphics: K. Kothieringer.

All colluvial deposits are decalcified and show pH-values in a range from 5.9 to 6.2 (Figure 3a). Charcoal fragments of the type oak collected from the lowermost colluvial deposits at two further locations in the sink date to the End Neolithic as well (nos. 3a, 5a, Table 2). Both the absolute soil depth in which these deposits were located (1.3–3.3 m) and the relative thickness of each of them (0.35–0.75 m) varied strongly; the pathway of the single deposits, however, could be traced very well along the sink.

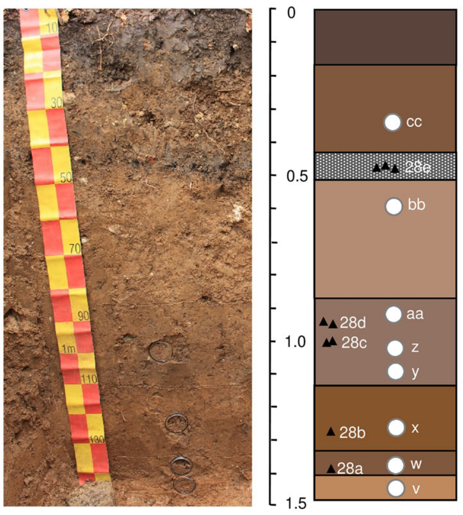
Our archaeological investigations at the Arnstein plateau show a significant prehistoric human impact on the landscape from the early 4th millennium B.C.E. until the Middle Iron Age. Presumable former settlement features located in recent arable land have been completely destroyed by soil erosion and are only present in the form of relocated soil material. Some burial mounds and a fortified settlement ('Heidenknock') can still be found in forested areas. The geoarchaeological investigations evidence a remarkably thick (about 1 m), Early to Middle Bronze Age colluvial deposit M1 in the vicinity of an undated settlement site. The Late Bronze Age to Middle Iron Age deposit M3 temporally matches anthropogenic activities around the prehistoric site 'Heidenknock' and evidences strong fire activities by an abundant amount of micro charcoal and burnt roots in this deposit. The upper colluvial deposits point to fire and land use activities later on in the Roman period, and from the High Medieval period to the Modern Era.

(c)



Horizon	Munsell color	TOC [%]	pH	$CaCO_3$ [%]	Texture weight [%]		
					< 2 µm	2–63 µm	63–2000 µm
Ap	10YR 5/4	2.16	7.03	3.6	28.9	57.6	13.5
M3	7.5YR 6/6	0.89	6.98	2.7	24.6	50.5	24.9
	7.5YR 6/6	0.85	6.95	2.4	26.7	51.2	22.1
	7.5YR 6/6	0.90	6.90	2.7	24.9	53.7	21.4
M2	7.5YR 3/2	1.06	6.74	2.6	34.9	61.2	3.9
M1	7.5YR 4/4	0.97	6.85	0.3	40.8	55.3	3.9
	7.5YR 4/4	0.96	6.91	0.2	42.7	51.7	5.6
2Bw	7.5YR 6/4	0.52	6.85	14.4	55.4	37.8	6.8

(d)



Horizon	Munsell color	TOC [%]	pH	$CaCO_3$ [%]	Texture weight [%]		
					< 2 µm	2–63 µm	63–2000 µm
Ah	7.5YR 3/2	6.12	5.78	0.0	22.0	54.6	23.4
M5	7.5YR 4/4	1.74	6.18	0.2	35.5	49.2	15.3
	7.5YR 4/4	1.69	6.21	0.1	38.5	50.7	10.8
fAh	7.5YR 3/1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
M4	7.5YR 6/4	0.85	6.52	0.2	31.3	60.2	8.5
	7.5YR 6/4	0.80	6.61	0.2	28.1	58.7	13.2
M3	7.5YR 5/3	0.72	6.98	0.1	28.0	63.3	8.7
	7.5YR 5/3	0.72	6.96	0.1	29.6	63.0	7.4
M2	7.5YR 4/6	0.83	6.95	0.2	30.4	61.7	7.9
	7.5YR 4/6	0.80	6.90	0.1	32.2	60.1	7.7
M1	7.5YR 4/4	0.61	6.88	0.0	36.4	58.2	5.4
2Bw	7.5YR 6/6	0.45	6.82	0.1	47.1	49.4	3.5

FIGURE 3 (Continued)

4.2 | Neudorf plateau (II)

4.2.1 | Archaeological results

No prehistoric sites were known at the Neudorf plateau until the beginning of this project. It was only during geoarchaeological fieldwork in the plateau area south of today's Neudorf village that several concentrations of stray finds were recorded, two of which were archaeologically investigated. The two sites *Neud131* (nos. 6–7, Figure 1) and *Neud122* (nos. 8–10, Figure 1) are separated from each other by a ca. 35 m wide sink that did not have any finds on the surface. However, it can be assumed that both sites belonged together, and that the deepest area is merely overlaid by a thick colluvial deposit.

At *Neud131*, located to the west of the sink, a settlement pit (Figure 2b) still 0.4 m deep, several small postholes less than 0.1 m deep and a small ditch with a trough-shaped profile were excavated in six small trenches. The ditch was observed over a length of about 10 m and could be interpreted as a farmyard enclosure. Such features have been occasionally found in Late Bronze and Iron Age settlements (Ostermeier & Pross, 2014). The archaeological features were covered by a medium-grey-brown colluvium, which, from west to east, showed an increasing thickness of 0.08 to 0.25 m. It contained medieval and modern sherds and therefore dates to this period.

Six small trenches were cut in the eastern part of the *Neud122* site. Also, here, a 0.07 to 0.45 m thick, colluvial, presumably medieval or modern overlay of prehistoric features was observed in the sections further downhill. The westernmost trench showed a sequence of

TABLE 3 Optically stimulated luminescence (OSL) ages in kiloyears (ka) with their 1σ uncertainties and the respective time periods (C.E./B.C.E.)

Name of plateau		Lab. no.	No.	Depth (m)	OSL age (ka)	OSL age (C.E./B.C.E.)
I Arnstein		GI 700	a	3.00/2Bw	24.45 ± 2.30	24732–20132 B.C.E.
		GI 703	b	2.40/M1	3.75 ± 0.31	2042–1422 B.C.E.
		GI 704	c	2.10/M1	3.83 ± 0.36	2172–1452 B.C.E.
		GI 705	d	1.85/M2	3.26 ± 0.34	1582–902 B.C.E.
		GI 706	e	1.60/M3	2.82 ± 0.31	1112–492 B.C.E.
		GI 699	f	1.40/M4	0.89 ± 0.09	1038–1218 C.E.
		GI 698	g	1.20/M4	0.53 ± 0.04	1448–1528 C.E.
		GI 697	h	0.60/M4	0.27 ± 0.02	1728–1768 C.E.
II Neudorf	onsite	GI 497	i	0.57	3.66 ± 0.27	1913–1373 B.C.E.
		GI 496	j	0.44	3.21 ± 0.21	1403–983 B.C.E.
		GI 495	k	0.34	2.75 ± 0.18	913–553 B.C.E.
	offsite	GI 379	l	1.00/2Bw	10.56 ± 0.81	9353–7733 B.C.E.
		GI 380	m	0.75/M1	1.76 ± 0.21	47–467 C.E.
		GI 381	n	0.62/M2	0.47 ± 0.04	1507–1587 C.E.
		GI 382	o	0.52/M2	0.42 ± 0.03	1567–1627 C.E.
		GI 383	p	0.42/M2	0.41 ± 0.03	1577–1637 C.E.
		GI 384	q	0.35/M2	0.30 ± 0.03	1687–1747 C.E.
III Görau		GI 616	r	0.90/M1	3.50 ± 0.24	1722–1242 B.C.E.
		GI 615	s	0.82/M2	2.98 ± 0.29	1252–672 B.C.E.
		GI 614	t	0.75/M2	2.67 ± 0.21	862–442 B.C.E.
		GI 613	u	0.55/M3	0.39 ± 0.03	1598–1658 C.E.
IV Wallersberg		GI 620	v	1.45/2Bw	9.01 ± 0.63	7622–6362 B.C.E.
		GI 619	w	1.40/M1	4.98 ± 0.45	3412–2512 B.C.E.
		GI 618	x	1.25/M2	2.30 ± 0.21	492–52 B.C.E.
		GI 491	y	1.12/M3	1.27 ± 0.11	638–858 C.E.
		GI 617	z	1.02/M3	1.00 ± 0.07	948–1088 C.E.
		GI 492	aa	0.90/M3	0.96 ± 0.08	978–1138 C.E.
		GI 493	bb	0.60/M4	0.86 ± 0.07	1088–1228 C.E.
		GI 494	cc	0.35/M5	0.80 ± 0.07	1148–1288 C.E.

Note: Besides the age, the sampling number, sampling depth in metres (m) in the undisturbed soil profiles or archaeological feature (i–k), and the respective soil horizon in the offsite context are given. Nos. i–q refer to 2017 (year of measurement), and nos. a–h and r–cc refer to 2018.

colluvial deposits of ca. 0.25 m thickness. Here, three OSL dates each show a single phase of soil erosion during prehistoric times probably over a period of at least 460 and at most 1360 years (nos. I–k, Table 3). A compound of pits and two postholes was recorded beneath the colluvium. The first posthole had a depth of nearly 0.60 m and the second posthole had a depth of 0.35 m. At both sites, we recovered around 450 prehistoric ceramic sherds, fragments of querns, and fired clay. Apart from a few sherds with sloping edges that belong to the Late Bronze to Early Iron Ages, no typochronological finds were present. Animal bones have hardly been preserved due to the decalcification of the soil; thus, nothing is known about the use of domestic and/or wildlife resources at this site. Macroremains were only present in the form of two ember grains. The charcoal fragments from the settlement features of both places originated mainly from oak, followed by beech and, to a lesser extent, from birch, hornbeam, ash, hazel, and pine. However, in the onsite colluvial layer, beech was the dominant species, followed by oak and, to a lesser extent, other deciduous tree species. The ^{14}C dating of *Fraxinus* revealed, similar to the Arnstein plateau, the first fire activities as early as the Younger Neolithic (no. 8a, Table 2). Some later dates of macroremains (*Triticum dicoccum*) and charcoal

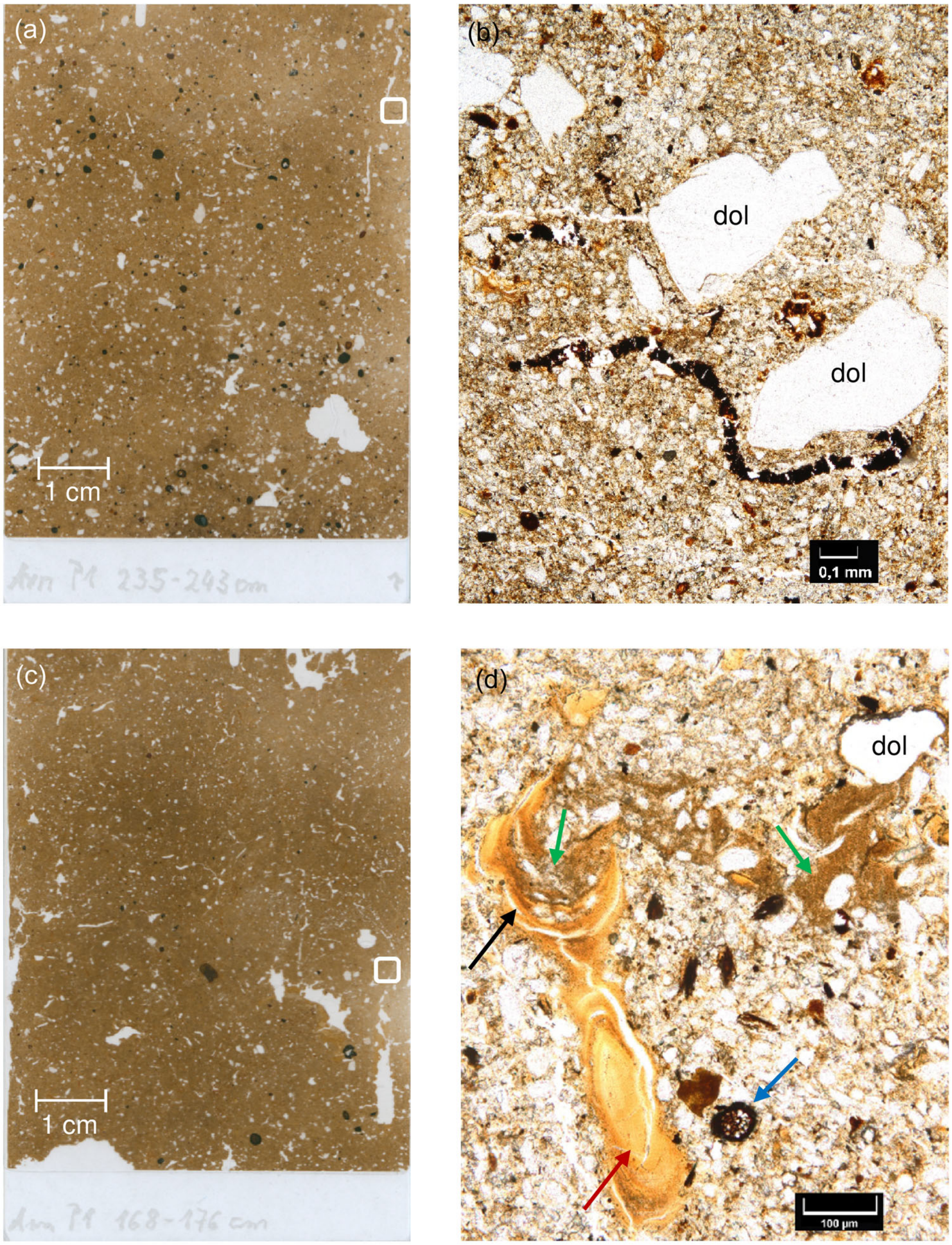


FIGURE 4 Micromorphological analysis of colluvial deposits M2 and M3 at Arnstein. (a) Scan of thin section from 2.35 to 2.43 m depth in Middle to Late Bronze Age deposit M2. Uniformous, humic soil matrix, typical for colluviation. Macroscopic dark and reddish, rounded features are naturally occurring Manganese and Iron nodules. Blackish amorphous features represent plantcoal fragments. The white square marks the section shown in Figure 4b. Scan: K. Kothieringer. (b) Exemplary record of burnt root and microscopic plantcoal (black dots) in M2. Dusty silty soil matrix. Coarse fragments of dolomite (dol) rock are only weakly weathered and slightly abraded, indicating a short distance of relocation. Photomicrograph: K. Kothieringer. (c) Scan of thin section at 1.68–1.76 m depth from humic, Late Bronze Age to Middle Iron Age deposit M3. Ground mass is similar to the one of M2 due to colluviation. Plantcoal is significantly stronger fragmented and finer dispersed than in M2. The white square marks the section shown in Figure 4d. Scan: K. Kothieringer. (d) Dusty soil matrix with fragmented plantcoal and soil fungi (blue arrow), typical indicators of humic soil conditions, in M3. For explanations of the origin of bright limpid clay coatings (black arrow) and darker dusty clay and silt coatings (green arrows), see Section 4.1.2. Clay infillings (red arrow) probably developed after the decay of organic matter. Photomicrograph: K. Kothieringer.

fragments (*Carpinus*, *Betula*, *Fagus*) fall into the Younger Urnfield period and the Iron Age (nos. 6a–b, 8b, 9a–b, Table 2). This seems to indicate a continuity of settlement activities even into the Early La Tène period (*Corylus*; no. 9c, Table 2). After a gap of about 600–700 years, several dates fall into the Late Roman period around 250 C.E. (*Carpinus* and *Fagus*; nos. 6c, 10a–b, Table 2). One ^{14}C dating (*Carpinus*) revealed an early medieval age (no. 7, Table 2). The charcoal fragment comes from the small ditch; however, it may be interpreted as a more recent find that had been relocated into an older feature, as there are no other indications of a medieval settlement at this site.

4.2.2 | Geoarchaeological results

Soil augering was conducted at a distance of about 200 m to the south and southwest of the archaeological sites in a shallow depression and in further channels and incisions along the plateau (nos. 11–15, l–q, Figure 1).

At location no. 11, the reworked *terra fusca* records an OSL age of 10.56 ± 0.81 ka (no. l, Table 3). In contrast to the Pleistocene age of the Bw horizon of Arnstein, this horizon is of Early Holocene age. Its formation is interpreted as natural and not human-induced, as wet-sieving of the soil material provided no (micro-)charcoal fragments or any other features related to past human activities. The colluvial sequence above the Bw horizon is formed by the deposits M1 (0.4 m thickness) and M2 (0.15 m). They can clearly be differentiated by their colour and grain size distribution (Figure 3b). At the transition of M1 to Bw, charcoal fragments (*Quercus*) date to ca. 2.8 ka B.P. (no. 11a, Table 2). The formation of M1, however, dates to 1.76 ± 0.21 ka (Roman period; no. m, Table 3). The presence of the offsite Roman period sediment correlates well with nearby onsite activities of this period, as revealed by our archaeological investigations (nos. 6c, 10a–b, Table 2).

In the uppermost M2 horizon, OSL samples taken between 0.35 and 0.62 m soil depth evidence three phases of colluviation during the last 250 to 500 years (nos. n–q, Table 3), but with very similar soil properties within the horizon (Figure 3b). A medieval sherd, not further definable with regard to age, was found at 0.60 m soil depth. Oak and pine (*Pinus*) charcoal fragments, all collected in M2, record ages both of the Late Bronze Age and the Modern Era (nos. 11b–c, Table 2).

The results of these findings are shown in Figure 5a,b. Within a short distance, we augered and dug the soil at several locations, following a catena from east to west (Figure 5a). At three locations, soil samples were dated by ^{14}C analysis and/or OSL (nos. 11–13; red, blue, yellow). Figure 5a furthermore illustrates both the setting of the onsite and offsite spots and the flow direction of the terrain, as indicated by the light green arrows. The age versus depth plot in Figure 5b highlights discrepancies between the ^{14}C ages of the three locations on the one hand and the OSL ages of the 'reference' soil profile on the other. Moreover, it clarifies the variability of the absolute thickness of the offsite colluvial bodies and the relative thickness of the deposits at each location. Based on the ^{14}C date of the lowermost colluvial deposit M1 at location 11 (red circle in Figure 5b), one could assume that this deposit is of prehistoric age. However, this is not supported by the OSL age of M1 (red triangle in Figure 5a), which indicates colluviation in the Roman period. Our interpretation is that older, Late Bronze Age charcoal was incorporated into the sedimentation cycle during erosion, sedimentation, and mixing of the soil material in the Roman period and, later on, in the Early Modern Era (M2). The same process can be assumed at location 13 (nos. 13a–d, Table 2; yellow circles in Figure 5b), where we found thicker deposits than at location 11 due to the more downslope topographical position.

At the westernmost location (no. 12, blue in Figure 5a,b), the colluvial body is the thickest of all (ca. 2 m), which may be attributed to the relief-induced 'push' and 'piling up' of sediments from the north, south, and east (Figure 5a). ^{14}C analysis of charcoal from M1 (*Fagus*) and M2 (*Abies*) evidences fire activities in the Early and High Medieval period (nos. 12a–b, Table 2). The medieval anthropogenic overprint is corroborated by ^{14}C dates from the lowest colluvial deposits at further spots (nos. 14–15, Figure 1; Table 2), where charcoal fragments of *Fagus* date to the Early Medieval period, respectively. This result is in contrast to the plateaus of Arnstein (Section 4.1.2), Görau (Section 4.3.2), and Wallersberg (Section 4.4.1), where all ^{14}C dates and OSL ages of the lowest colluvial deposits recorded prehistoric ages.

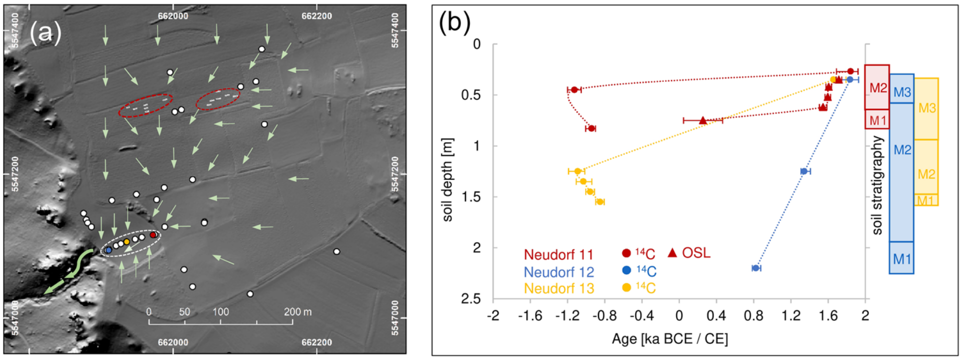


FIGURE 5 (a) Setting of the onsite and offsite spots and the flow direction of the terrain (light green arrows) based on GIS analysis ('flow direction') at the investigated section of the Neudorf plateau. Map frame with UTM coordinates. Red ellipses mark the areas of archaeological features in the north; the white ellipse marks the offsite sink with several undated augering locations (white circles) and dated spots (coloured circles, see legend) in the south. *Source*: DEM (1 m): Bayerische Vermessungsverwaltung. Graphics: K. Kothieringer. (b) Age versus depth plot for the Neudorf offsite colluvial deposits. OSL ages (triangles) and calibrated ^{14}C ages (circles) of charcoal fragments—both shown with their median values and 1σ uncertainties—are plotted versus the soil depth (left *y*-axis) for locations 11 (red), 12 (blue), and 13 (yellow). OSL ages are in stratigraphic order, whereas the age information based on charcoal can be misleading due to reworking and later incorporation in the deposits. Soil stratigraphies of the locations are shown along the second *y*-axis. For details, see Section 4.2.2. Graphics: K. Kothieringer.

Excavated settlement structures on the Neudorf plateau date to the Late Bronze and Iron Ages. Several charcoal fragments from the offsite context confirm local fire activities during the Late Bronze Age. Earlier human activities from the Early or Middle Bronze Age, however, can be inferred from very shallow onsite colluvial deposits. After a hiatus from 250 B.C.E. onwards, settlement activities were resumed in the Late Roman period. This result is corroborated by the presence of a temporally matching, offsite colluvial deposit in a nearby pronounced sink. The terrain is covered by colluvial deposits of the Medieval period and the Modern Era, which must have prevented the erosion of the prehistoric archaeological features and the onsite prehistoric colluvial deposits, if only on a small scale. On the other hand, the medieval and modern anthropogenic overprint probably was responsible for severe erosion, thorough mixing, and possible 'dissolution' of older prehistoric colluvial deposits in the offsite sedimentation cycle.

4.3 | Görau ridge (III)

4.3.1 | Archaeological results

The area of the 'Görauer Anger' (Görau ridge) had been known as a prehistoric site for quite some time. There is a barrow field about 450 m north of the northwest–southeast-oriented ridge, partially destroyed by improper excavations in the 19th century (Hermann, 1842; Schwarz, 1955). The finds from this site, including a bronze sword, a heel ax, needles, and fibulas, date back to the late Middle Bronze Age and the Late Hallstatt/Early La Tène periods (Berger, 1984; Hoppe, 2011). Our archaeological investigations started at the known stray find area on the elongated ridge. Based on preliminary results of the magnetic prospecting and field survey, a total of 21 trenches were excavated at three locations.

The area of *Neud1509* (nos. 16–17, Figure 1) is strongly affected by erosion. Here, in an apparently natural depression, a ca. 0.10 m thick cultural layer and a 0.15 m deep posthole could be documented. Judging from the ^{14}C dates of macroremains (*Hordeum vulgare*, *Betula*, *Corylus*, and Maloideae, nos. 16a–d, Table 2), the cultural layer, which contained a considerable number of prehistoric sherds, was strongly mixed and probably deposited in this small sink through erosion in historical times. Charcoal (*Fagus*) sampled in the small posthole dates to the Hallstatt period (no. 17, Table 2).

At the *Neud1500* site (nos. 18–19, Figure 1) located ca. 250 m southeast, we recorded a slight depression in the three western trenches, filled with a 0.10–0.35 m thick colluvium. In addition to prehistoric ceramics, this layer also contained fragments of querns, which indicates settlements destroyed by erosion. The three small trenches further to the east yielded four postholes with a maximum depth of 0.30 m (Figure 2c). The ^{14}C dates of *Hordeum vulgare* and *Triticum dicoccum* as well as the typochronologically significant finds indicate phases of use in the Early to Middle and Younger Urnfield period, that is, around the 13th to 9th centuries B.C.E. (nos. 18–19, Table 2).

At the *Neud1497* site (nos. 20–23, Figure 1) immediately to the south, we identified three postholes and a colluvial deposit with a maximum thickness of 0.15 m (Figure 2d) as well as a storage pit about 0.80 m deep (Figure 2e). The pit with a diameter of ca. 0.95 ×0.85 m widens like a truncated cone in the lower part. After losing its primary function as food storage, it was filled with numerous finds, among them larger fragments of ceramic vessels and broken stone utensils, including querns and grinding stones. The preservation of a complete tiered vessel (Figure 2f), two almost complete conical cups (Figure 2g,h), and parts of a bowl (Figure 2i) is remarkable. In contrast to the other sites, animal bones have been preserved: the spectrum comprises 48 pieces (154 g) of bones from sheep or goat, 22 pieces (165 g) from pig, 18 pieces (243 g) from cattle, and one piece of bone each from horse, red deer, fox, and brown hare. Based on the finds and the ^{14}C dating of *Triticum dicoccum*, the pit dates to the Middle Urnfield period (nos. 22a–b, Table 2). Further dating of macroremains from the postholes *(Fagus*, Maloideae and *Triticum dicoccum)* falls into the Middle Bronze Age and the Early to Middle and Younger Urnfield period (nos. 20a–b, 21, 23a–b, Table 2).

4.3.2 | Geoarchaeological results

The central part of the Görau ridge has, for the most part, been eroded. Small-scale, human-induced relocation of sediments was also determined in minor depressions directly on the ridge. Nevertheless, we expected to find the major portion of colluvial deposits at northern and southwestern footslope positions. Soil augering following a catena along the southwestern slope evidenced a modern plough horizon above the *terra fusca*, without any colluvial deposits in between. The corresponding deposits were found in an adjacent enclosed sink. The characteristics of a soil profile that we dug in the sink to allow for undisturbed sampling will be described in the following (Figure 3c). The OSL ages are all in stratigraphic order and in accordance with the ^{14}C ages.

The *terra fusca* (identifiable in Figure 3c in the planum of the soil pit by the presence of coarse, weathered dolomite fragments) was not sampled for OSL analysis at this point. M1 is clay-rich and represents the oldest colluvial deposit in the sequence, with an OSL age of 3.50 ± 0.24 ka (no. r, Table 3). Charred beech sampled in M1 at about 1.02 m depth dates to the Early Bronze Age and, at 0.9 m, to the Middle Bronze Age (nos. 24a–b, Table 2). Charred fragments of Maloideae recovered by augering and sampling of M1 at a distance of a few metres from the soil pit date to the Middle Bronze Age as well (no. 25, Table 2).

In the 0.15 m thick horizon M2, charred oak, macroremains of bedstraw (*Galium*), and remains of unspecifiable wood indicate fire activities from the Late Bronze Age, the Early to Middle Iron Age, and the Middle to Late Iron Age (nos. 24c–e, Table 2). This is in temporal accordance with two OSL samples taken from M2 that recorded ages of 2.98 ± 0.29 ka and 2.67 ± 0.21 ka (nos. s–t, Table 3). It thus indicates two phases of soil erosion. The TOC content in M2 is the highest of all colluvial deposits (Figure 3c). In the uppermost colluvial deposit M3 of almost 0.50 m thickness, charcoal fragments of the type coniferous wood date to the Modern Era (no. 24 f, Table 2). OSL dating at 0.55 m depth underlines the occurrence of colluviation 350–400 years ago (no. u, Table 3).

At the foot of the steep northern slopes of the ridge, which geomorphologically has to be regarded as an 'open sink', we found prehistoric anthropogenic features through soil augering that must have originated from the former plateau settlements or from human activity on the slopes. The stagnic soil horizon in which the charcoal (no. 26a, Table 2) was collected consisted of reworked soil material strongly affected by waterlogging after deposition. It also comprised small fragments of prehistoric sherds. As all colluvial deposits examined along the foot of the northern slopes are only a few cm thick, it may be assumed that they have been affected by steady soil erosion and relocated to positions further downslope.

In archaeological terms, settlement activities at Görau took place from the late Middle Bronze Age (14th century B.C.E.) throughout the entire Urnfield period (ca. 13th–9th century B.C.E.) until the Hallstatt period (8th–6th century B.C.E.). Erosion in prehistoric times, and predominantly in historical times, led to the complete destruction of the settlement features in some areas of the site. We detected Middle Bronze Age to Middle Iron Age colluvial deposits in a southern enclosed depression, which temporally match the settlement activities along the ridge very well. Colluviation in the Early Modern Era must have been strong, as evidenced by the 0.5 m thick deposit M3 in the southern sink.

4.4 | Wallersberg plateau (IV)

4.4.1 | Archaeological and geoarchaeological results

The plateau of Wallersberg was a major target of our earlier investigations of Bronze and Iron Age settlements as well as land use dynamics in the study area (Kothieringer et al., 2018). Further archaeological surface surveys, geophysical prospecting, and soil augering revealed two settlement features (remains of pits) on this promontory, dating back to the Hallstatt and Early La Tène period (nos. 27a–b, Table 2).

Offsite, a soil pit was dug on the nearby forested southern slope, where colluvial deposits from the promontory had accumulated and were distributed in the form of a small-scale terrace, which probably formed above a geological ledge at this steep location. The OSL sample of the Bw horizon at about 1.45 m records an age of 9.01 ± 0.61 ka (no. v, Table 3), which is comparable to the Early Holocene age of the Bw horizon at the Neudorf plateau (Section 4.2.2). Above Bw, the colluvial deposit M1 gives an OSL age of 4.98 ± 0.45 ka (no. w, Table 3), which represents the oldest evidence of human-induced soil erosion in our study area. The Late Neolithic age is confirmed by ^{14}C dating of charcoal (of unspecifiable type) collected at the same soil depth from which the OSL sample was taken (no. 28a, Table 2).

Above M1, the colluvial deposit M2 records increased TOC contents of about 0.8% (Figure 3d) at an OSL age of 2.30 ± 0.21 ka (no. x, Table 3), which very well corresponds to the temporal setting of the nearby archaeological features on the promontory. The ^{14}C age in M2 (no. 28b, Table 2) overestimates the age of deposition, which can be explained by either the incorporation of old organic material or the heartwood effect of oak, or both. OSL samples of M3 and M4 gave ages from the Early to High Medieval periods (nos. y–bb, Table 3). Analysis of charcoal from M3 evidences the burning of broad-leaved tree species such as poplar (*Populus*) or willow (*Salix*), and blackthorn (*Prunus*) in the Early and High Medieval period (nos. 28c–d, Table 2). In M4, the amount of the collected charcoal was too small for ^{14}C analysis; however, a rather high TOC content of about 0.82% (Figure 3d) speaks to an abundance of (un-)charred organic matter in this horizon.

Above M4, we found a thin burnt layer (fAh, Figure 3d) at about 0.45 m soil depth with in situ charcoal of Maloideae that dates to 0.606 ± 0.022 ka B.P. (no. 28e, Table 2). The colluvial deposit M5 above the fAh horizon, however, gives an older OSL age of 0.80 ± 0.07 ka at 0.35 m depth (no. cc, Table 3). As there is no overlapping of the dates within their 1σ errors, we assume that fire activities and colluviation took place nearly simultaneously around 1300 C.E., at which the two time spans converge.

The Wallersberg plateau must have been strongly affected by forest clearance and soil erosion in historical times, as indicated by Early to High Medieval colluvial deposits and a High Medieval burnt layer from the offsite context. Despite severe erosion, we detected two Iron Age pits as remains of former settlement sites on the plateau, as well as temporally matching offsite colluvial deposits from Iron Age land use. Older settlement features were not found, but from the offsite colluvial deposit, we know that human activities must have started much earlier, that is, in the Late Neolithic.

5 | DISCUSSION

5.1 | Settlement and landscape dynamics since the Neolithic

5.1.1 | Neolithic

Even if traces of settlement from the Neolithic have not yet been recorded in the study area, the first fire activities on the plateaus of Arnstein and Neudorf, evidenced by charcoal finds in colluvial deposits, occurred in the late 5th to early 4th millennium B.C.E. (Younger Neolithic). At the Wallersberg plateau, early evidence of fire activities and coinciding colluvial formation dates to the mid-4th to mid-3rd millennium B.C.E. Anthropogenic activities must have occurred on a larger spatial scale at that time, as colluvial deposits of about the same age were recorded by OSL dating in the Franconian Jura further south of our study area (Fuchs et al., 2011).

Since neither archaeological sites nor dated colluvial deposits of the Early or Middle Neolithic are known from the valley, initial settlement of our study area must have taken place around 1200 years later than on the northwestern Franconian Jura (Seregély et al., 2015), that is, during the Younger Neolithic. From these beginnings, it is still unclear if the study area was continuously settled until the End Neolithic. What we know is that settlement activities were revived during the End Neolithic at the latest, between 2800 and 2500 B.C.E., presumably by settlers of the Corded Ware culture. Evidence of this can be found both in the small northern Franconian Jura valleys (Seregély, 2013) and in the plateau region, for example, the burial mound of Neudorf-Azendorf (Hock, 1933; Seregély, 2008), as well as through ^{14}C dates from colluvial deposits on the Arnstein plateau (Table 2).

As mentioned in Section 4.1.2, the ages of the charcoal fragments (nos. 3a, 4a, 5a, Table 2) of the Arnstein sink are possibly overestimated due to the heartwood effect of oak. Thus, the tree felling date could be several hundred years younger and therefore would correspond to the Early Bronze Age date of the colluvial deposit itself. Interpreting the ^{14}C dates of the End Neolithic, however, we consider the charcoal fragments as indicators of a first, only local and limited clearance of oak forest by fire to open land for human activities. Human-induced soil erosion must have been negligible, as we do not see evidence of a specific End Neolithic colluvial deposit by OSL dating, indicating the time of colluvial deposition and therefore erosion. On a supra-regional scale, Late to End Neolithic human activities were also evidenced in the pollen record of mires at elevated mountain ranges such as the Northern Black Forest in southwest Germany (Rösch, 2012). Land use practices at that time did not necessarily lead to a steady deforestation and the development of open replacement communities such as permanent grassland (Kalis et al., 2003; Rösch, 2012). During the Late to End Neolithic, unspecified land use activities in a grass-dominated landscape are also known from other regions in southwest Germany (Scherer et al., 2021).

Taking into account the absence of End Neolithic settlement features at Arnstein, the degree of expansion of the cultivated areas cannot be deduced from our offsite colluvial data. However, it is probable that areas for cultivation were rather small, were used sporadically, and moved steadily, as assumed by Rösch (2011; 2012) for the northern Black Forest.

5.1.2 | Early and Middle Bronze Age

Clear evidence of settlements from the Early and Middle Bronze Age is still missing from the plateaus. However, metal artefacts and burial finds in the vicinity (Hermann, 1842; Hoppe, 2011; Seregély, 2008) as well as radiocarbon and OSL data from colluvial material of the plateaus of Arnstein, Görau, and Neudorf (the latter onsite) suggest settlement in these areas. It is possible that a specific way of building the houses, for example, sill beam constructions, and soil erosion led to the complete destruction of the former settlement structures from this period. This has already been proven for the Corded Ware culture of the End Neolithic (Seregély, 2008, 2012c). Those sill beam constructions or block huts have only survived because of the slightly deepened interior areas (so-called 'sunken floors') in what are now mostly forested areas. In non-forested areas, such features have been almost completely destroyed by erosion (Hendel, 2012). It is also conceivable that dwelling places on the plateaus at that time were not necessarily permanent settlements, but rather temporary campsites in the context of seasonal hunting or herding activities.

Climatic events in the younger Middle Bronze Age should also be considered as triggers for changes of the settlement structure. In the oldest dated valley settlement near Kaspauer (V, Figure 1; no. 29, Table 2), settlement activities were discontinued during the younger Middle Bronze Age (around 1300 B.C.E.), followed by strong erosion and complete filling of a palaeoriver channel (Seregély, 2013), which in turn must have been caused by heavy precipitation.

In comparison to more frequent and partly stronger climatic fluctuations in the Neolithic, the Early and Middle Bronze Ages could be regarded as a climatically rather 'quiet' period (Gronenborn, 2011). However, the synopsis of palaeoclimatic proxy data, such as the production rate of ^{14}C (e.g., Kromer & Friedrich, 2007), ice rafting detritus-events (e.g., Bond et al., 2001), GRIP δ^{18}O ice-core data (e.g., Vinther et al., 2006), δ^{18}O data from alpine lake sediments (e.g., Von Grafenstein et al., 1999), and glacier extensions in the Eastern Alps (e.g., Nicolussi et al., 2005), allows for a detailed reconstruction of momentous events such as the so-called 'Löbben-Oscillation/cold event (C.E.) 7' (e.g., Bortenschlager & Patzelt, 1969; Haas et al., 1998; Wipf, 2001), a period of climatic deterioration from about 1600 B.C.E. with rather cool and humid conditions in central Europe. Climatic oscillations occurred continuously in the centuries after this event. Further supra-regional evidence of more humid conditions during the Middle Bronze Age in east-central Europe can be derived from isotope geochemical proxies from stalagmites in Hungarian caves (Demény et al., 2019). Moreover, based on a highly resolved, regional climatic record of the depositional frequency of subfossil oaks of the Main river and its tributaries (such as the Weismain river) since about 8000 B.C.E. (Spurk et al., 2002), we assume increased river discharge and more flooding events in the 14th and 13th century B.C.E. in the study area. Changes in the water regime of rivers should rather be attributed to climatic triggers, that is, to more humid conditions, than to a predominantly human impact at that time (Spurk et al., 2002). A higher risk of flooding in the small V-shaped valleys of the study area could explain the increase in settlement sites from the younger Middle Bronze Age on the northern Franconian Jura plateau (Berger, 1984). The development of new, flood-proof settlement territories at this time is also indicated by ^{14}C dates presented here (Arnstein, no. 2b; Görau, nos. 16a, 20a, 24b, 25; Wallersberg, no. 28b; all in Table 2).

Also remarkable is the thickness of the Early to Middle Bronze Age colluvial deposit M1 of ca. 0.4–1.0 m at various locations in the sink of Arnstein. The deposit did not comprise any material fragments, for example, sherds, but an abundant amount of micro and macro plantcoal and burnt roots; thus, we interpret the deposit as evidence of intense clearing and not as eroded settlement remains. Besides clearing, the local, potentially agricultural use of the slopes probably caused severe erosion of the Early and Middle Bronze Age favourable loess soils. The formation of Early and Middle Bronze Age colluvial deposits due to land use activities has been reported previously from southern and central German uplands (e.g., Fuchs et al., 2011; Henkner et al., 2017; Henkner, Ahlrichs, Downey, et al., 2018; Henkner, Ahlrichs, Fischer, et al., 2018; Stolz et al., 2012). However, in some upland regions of this period, colluvial deposits can be absent as well (Knapp et al., 2013; Scherer et al., 2021). This indicates that land use practice may have played a key role in triggering soil erosion, for example, assuming that seasonal and sporadic land use with pastoral activities was predominant at that time (Rösch, 2012). This type of land use did not necessarily leave significant traces in the form of colluvial deposits. In comparison to Arnstein, the Early to Middle Bronze Age deposit found in the southern Görau sink is thin (about 0.1 m), indicating a less intense kind of land use that did not lead to a high degree of soil erosion, for example, by pastoralism. As the dry calcareous grasslands on the Görau ridge and the northern slopes are nowadays still used for extensive sheep grazing, (forest) grazing in the longue durée since the Early Bronze Age seems likely for this area. However, we cannot exclude contemporary agriculture on the surrounding slopes of the Görau ridge: an early type of farming probably included long fallow periods, allowing the organic matter in the soil to accumulate again (Styring et al., 2017; Tserendorj et al., 2021), which, in turn, did not necessarily lead to severe soil erosion and the formation of colluvial deposits. What we know is that local clearance took place on the southern slopes of the ridge, as indicated by Early to Middle Bronze Age charcoal remains of trees (*Fagus)* and shrubs (Maloideae) found in the offsite context.

5.1.3 | Late Bronze Age

A peak in Late Bronze Age (10th and 9th centuries B.C.E.) settlement activities is known from all four of the investigated plateaus (Kothieringer et al., 2018). As evident in Neudorf, settlement activities did not cease afterwards during the transition to the Hallstatt period (ca. 800 B.C.E.), even though settlement or burial inventories are unknown for this period.

Reasons for an increase in settlement activities on the plateaus are probably diverse and should be regarded on a supra-regional scale. For our study area, mining activities that are considered as the driving force of an increase in settlement activities, husbandry, and agriculture in other southern German regions during the Late Bronze Age (Rösch, 2012) can be neglected due to the lack of natural resources (ores). During the Middle to Late Bronze Age transition, however, first permanent fortifications occurred on prominent hilltops in the wider area of Northern Franconia, for example, the Ehrenbürg (Abels, 2012), the Bullenheimer Berg (Diemer, 1995), or the Kahlberg in the vicinity of Görau within our study area (Ostermeier, 2012). Here, we propose a social and functional relation between the Kahlberg hilltop and the Görau ridge, as the hilltop lies in a direct line of sight of ca. 1.7 km distance from the ridge and shows the same settlement phases as the ridge. Considering the rich burial furnishment of the Görau mounds in the Metal Ages (e.g., a Middle Bronze Age sword, Section 4.3.1), this burial ground was presumably used by an 'elite'. The 'elite' settlement ground was rather located on the Kahlberg, as no corresponding finds and/or traces of fortifications were present in the Görau settlement, indicating that the population on the ridge was probably not of an 'upper' social status.

The supply of these hilltop fortifications or settlements, such as the Kahlberg, certainly required a strong economic base, such that the agricultural use of the nearby narrow valley floors was no longer sufficient. This may have led to an expansion of settlement activities up to the surrounding plateaus, which were still covered by substantial loess soils at that time. On the plateaus, larger areas were available for agriculture after forest clearance by slash-and-burn and concurrent (forest) grazing. Repeated flooding events in the narrow valleys of our study area, as already discussed for the Middle Bronze Age, could also have been a trigger for a shift of the settlement to the plateaus.

At Neudorf, Late Bronze Age fire activities are indicated by charcoal in offsite colluvial deposits, which temporally match the nearby archaeological features. Taking into account the errors of the OSL ages of the colluvial deposits M2 and M3 at Arnstein (nos. d, e, Table 3), we can distinguish two phases of soil erosion: Middle to Late Bronze Age, and Late Bronze Age to Early Iron Age, leading to ca. 1 m thick colluvial deposits. This indicates an intense (re-)opening and use of the landscape. Late Bronze Age colluvial deposits that coincide with the settlements were also located at Görau. Considering the current state of preservation of the postholes of ca. 0.2–0.5 m depth on the Görau ridge and assuming that the posts of the former houses or buildings had to be dug at least 1.5 m deep in the ground due to static reasons, we propose a loss of soil of more than 1 m since the late Middle Bronze Age, which probably increased during the Late Bronze Age. This indicates a major remodelling of the landscape relief. On a supra-regional scale, Late Bronze Age agricultural intensification is known, for example, from numerous pollen records in southwestern Germany (Tserendorj et al., 2021). Compared with earlier periods, ploughing techniques had probably been improved and fallow periods were shortened to meet the rising demand of cultivation products. The lack of organic matter in arable soils could be compensated by manuring (Rösch, 2011; Tserendorj et al., 2021). At Görau, the few preserved cereal residues in the spectrum of macroremains date to the Late Bronze Age, indicating nearby cultivation and further processing of cereals on the ridge.

5.1.4 | Iron Age

Settlement activities are traceable up to the Early La Tène period (ca. 450–350 B.C.E.). From the Middle La Tène period onwards, most likely a hiatus occurred that affected both the settlement and land use of the northern Franconian Jura plateaus. This might be related to the 'Celtic migration', even though its nature and dimension are highly debated (Alt & Schönfelder, 2017). For the local situation in Franconia, however, Abels (2012) as well as our own data clearly indicate the abandonment of settlements from the 4th century B.C.E. onwards. There is also no indication of intensive land use in the study area during the Late La Tène period.

In the offsite context at Arnstein, we were able to trace a hiatus of colluvial sedimentation starting in the Early La Tène period, which we associate with local-scale geomorphodynamic stability. This phase of slope stability must have occurred after the deposition of the colluvial deposit M3 from about 500 B.C.E. to 1000 C.E. Thus, there was sufficient time for the postdepositional formation of pedogenic features such as limpid clay coatings, as evidenced by our micromorphological analyses of the horizons M2 and M3. The onset of the hiatus at about 500 B.C.E. was also recorded at Görau. Here, it even lasted until the Early Modern Era.

As evidenced by colluvial deposition, human activities took place at Wallersberg in the Early La Tène period. This correlates well with settlement activities on the promontory during that period.

5.1.5 | Roman period and Migration period

The centuries of the Roman period represent a phase for which we initially expected only a few settlement activities and thus landscape stability and reforestation on the plateaus of the study area, since our archaeological investigations revealed Roman period activities only in the valleys (nos. 30a–b, Figure 1, Table 2). However, we found increasing evidence for a resurgent use of the plateaus during the Late Roman period and during the Migration period (3rd– 5th century C.E.). Based on colluvial deposits from Arnstein and Neudorf as well as dated charcoal from Neudorf and Görau, obviously, a resettlement of the unfavourable locations of the Jurassic plateaus took place in the Late Roman period. However, there were exceptions, since from about 50 B.C.E. to 650 C.E., no land use activities were recorded at the Wallersberg plateau. Evidence from archaeological finds is still missing. An influx of Burgundian, that is, East Germanic settlers into northern Bavaria, which was originally populated by Elbe Germans and an associated increase in population, has been discussed for this period (Haberstroh, 2000). Starting around 500 C.E., settlement activities apparently ceased again.

5.1.6 | Medieval period to Modern Era

In our study area, the first signs of the Carolingian territorial expansion and the associated increased land use activities can be identified through ^{14}C dates from colluvial deposits at the Neudorf plateau in the 8th century. The settlement that later became the city of Weismain is first mentioned in documents of the monastery of Fulda around 800 C.E. In 1972, an early medieval cemetery from the 8th and 9th centuries was discovered in the vicinity of the town centre. It contained 209 graves, some of them well furnished, which indicates the relative wealth of the inhabitants at that time (Sage, 1986). Our data suggest a subtle exploitation of the plateaus before, or in the course of the foundation of the settlement of Weismain from the 7th to 9th century. Presumably, the initial settlers were Slavs (Hoppe, 2011; Losert, 1993; Schwarz, 1984). Ongoing human presence and land use activities in the High and Late Medieval period, as well as in the Modern Era, are reflected by the offsite geoarchaeological data at all four plateaus. However, these periods have not been a focus of our research, and are thus not further discussed here.

5.2 | Plateau woodland composition

Considering the investigated sites and their topography, charcoal finds reflect the local vegetation, as charcoal could not have been transported over longer distances. The high proportion of pine charcoal in the offsite profiles of Neudorf (Figure 6, Section II) indicates that charcoal had not solely been relocated from the archaeological context, but that it predominantly came from other fire events. Overall, *Pinus* occurs in recent contexts, that is, upper deposits. The only ^{14}C dating of a *Pinus* charcoal dates back to modern times and thus points to recent fire events. From the relative absence of pine in the charcoal spectrum of the older (lower) deposits, we cannot deduce, however, that pine was not present in the natural vegetation in prehistoric times. Vegetation analyses from the southern Franconian Jura (Baumann, 2006) showed that pine—besides oak and others—frequently occurred in the natural vegetation in the Bronze Age and earlier. Our findings are probably skewed due to too small a sample number.

There are further differences between the onsite and offsite sample material, but these are largely reflected in the proportions between beech and oak or relate to rarely occurring species. Overall, both archives show the same vegetation and together give an impression of the landscape and its composition. The significantly lower number of pieces in the individual offsite samples must be taken into account in the evaluation, so that in Figure 6, only trends can be derived in terms of time and typology. Overall, charcoal from onsite features and from offsite colluvial deposits was mainly in a poor state of preservation due to soil erosion, which hampered the palaeoecological analysis and limited the number of determinations, especially in the offsite context.

On all plateaus, forest vegetation consisting of oak and beech was dominant in prehistoric times and thus reflects a typical deciduous forest community, before beech became dominant. The shift from an oak-dominated forest to a beech-dominated forest cannot clearly be dated in the study area so far, but seems to take place in the Iron Age and may be related to a lower human impact than in the periods before. Even if oak was of greater importance as timber, we do not think that oak was overrepresented in the material, since the origin of charcoal (fireplaces, slash and burn, house fires) is unclear. Other types of deciduous forests such as maple and hornbeam are only found sporadically. Due to the location of the studied sites, ash is rated as a pioneer wood and not as an indicator of wetland vegetation, whose presence on the plateaus can be ruled out anyway.

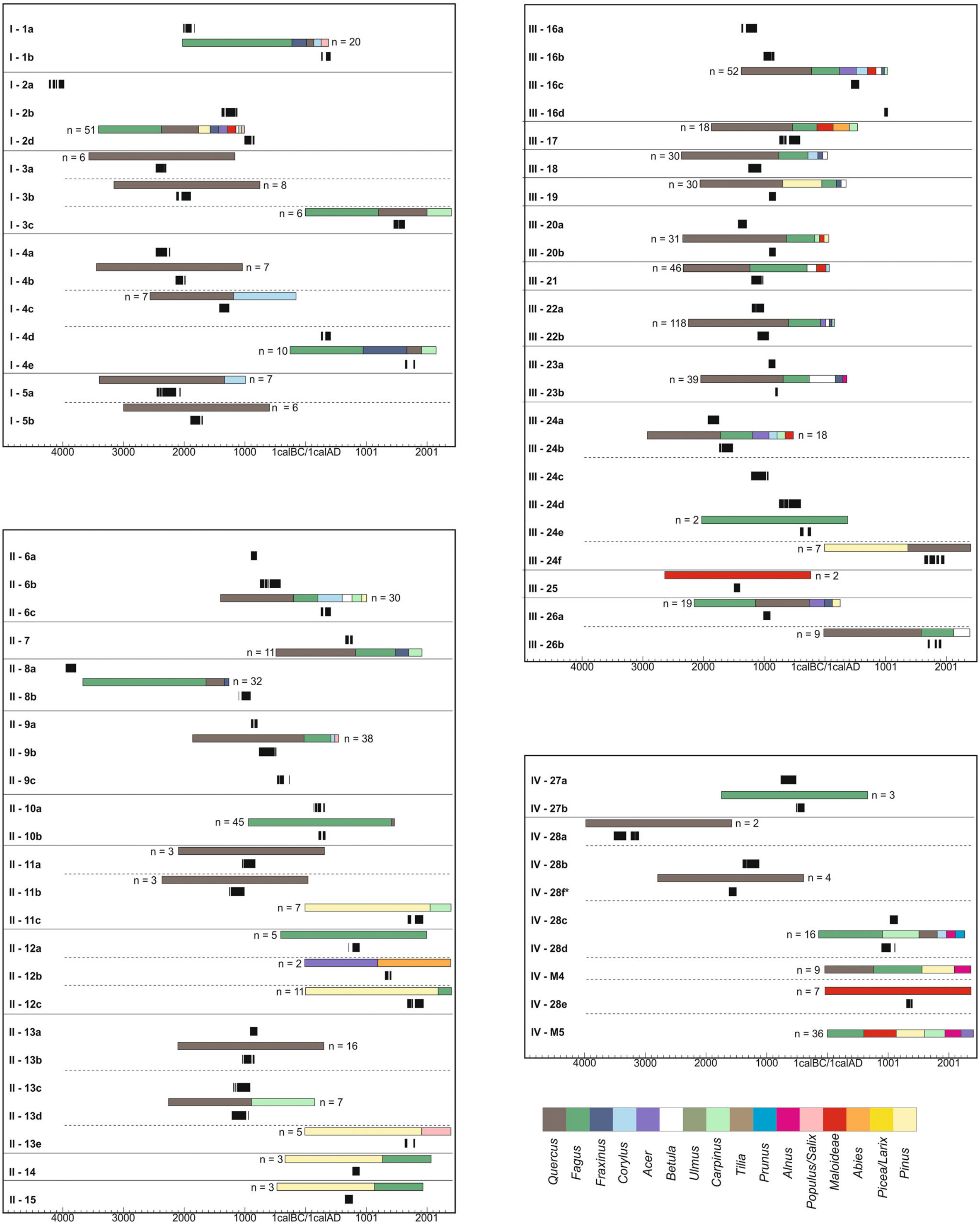


FIGURE 6 (See caption on next page)

In addition to ash, birch, hazel, poplar-willow type as well as Maloideae (pomaceous fruit) and *Prunus* (sloe/cherry) are also rated as indicators of a landscape opening. The proportion of these indicators exceeds 10% per site, except at Neudorf (7% onsite and 1.5% offsite), whereas Wallersberg stands out with 31% indicators of openings in the offsite site material. The role of the species of the Maloideae group in charcoal material has been a matter of debate for a long time. Among others, four theories have been proposed: (1) the use of cultivated fruits such as apple or pear (Schroedter et al., 2011), (2) the creation and use of hedges (Kreuz, 1990, 1992), (3) natural occurrence, for example, hawthorn (O'Donnell, 2017), and (4) their increased occurrence as successional indicators after clearing (O'Donnell, 2017; Salavert & Dufraisse, 2014). Both hawthorn and the wild types of apple and pear still occur in the study area today. We rate theory (4) as most probable for Görau, as, due to the long continuity of the settlement, it can be assumed that the pioneer trees and shrubs growing in the surrounding area had to be constantly cleared to keep the usable areas open. Originally forested, the Görau ridge is nowadays characterized by dry grassland vegetation used for extensive sheep grazing; however, some areas are subject to heavy shrub encroachment.

At present, it is assumed that firs (*Abies*) had no natural growth potential on the northern Franconian Jura. Kölling et al. (2004) assume that fir cannot compete against poorly growing beech trees if it grows in locations that are too dry. Rare finds of charcoal from fir (no. 12b, Table 2) indicate that this species was originally found on the plateau. Juniper (*Juniperus*), typical for present-day open vegetation on slopes, is entirely missing from the sample material.

6 | CONCLUSION

Our (geo-)archaeological investigations on Mid to Late Holocene rural settlement and landscape dynamics allow us to draw the following conclusions for the northern Franconian Jura:

1. The beginnings of Neolithic settlement activities cannot be precisely determined due to the lack of clear settlement traces. However, we identified several indicators of fire activities, most probably from first woodland opening, in colluvial deposits dating to the late 5th to early 4th millennium B.C.E. (Younger Neolithic). Further evidence of fire activities and coinciding colluvial formation dates to the mid-4th to mid-3rd millennium B.C.E. Just as for the Neolithic, clear evidence of settlement from the Early Bronze Age is missing from the uplands. However, metal artefacts and burials in the vicinity of the study area as well as several ^{14}C and OSL dates from colluvial deposits suggest Early Bronze Age settlement activities on the plateaus.
2. For the first time, here, we present evidence of Middle to Late Bronze Age permanent rural settlement sites in a German central upland region, comprising, for example, a variety of unambiguous features such as postholes and pits. We observe a peak of settlement activities in the Late Bronze Age. Later on, there is an almost continuous use of the landscape until the 5th century B.C.E. After a hiatus from the Middle La Tène to Middle Roman period, an expected re-flourishing of settlement activities and land use in the Late Roman and Migration periods (middle 3rd–5th century C.E.) was observed.
3. The combined methodological approach has enabled the detection of both various rural settlement sites and site-specific, temporally matching colluvial bodies caused by former soil erosion. Based on on- and offsite charcoal spectra, trends in woodland changes throughout time can be inferred, from beech and oak-dominated deciduous forests in prehistory to pine–beech-dominated mixed forests in historical/modern periods. The species Maloideae already appears in several Middle to Late Bronze Age features and deposits at Görau and, among other species, points to continuous clearing to maintain open areas.
4. The partially great thickness of prehistoric colluvial deposits possibly indicates the type of former land use practice, showing the extent of soil allocation over time and leading to a major remodelling of the landscape relief.
5. The supposedly climatically unfavourable plateaus of the northern Bavarian uplands were settled since the Younger Neolithic, but with varying intensity that did not always cause soil erosion or the formation of colluvial deposits.
6. It was confirmed that settlements were primarily established at the margins of the spurs, where freshwater sources (e.g., springs at the geological strata boundaries) were accessible, in contrast to locations of the inner plateaus (Kothieringer et al., 2018).

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FIGURE 6 Composition of vegetation through time based on charcoal analysis and ^{14}C dates from archaeological features and colluvial deposits at the four upland regions. Top left: Arnstein (I, 1a–5b); bottom left: Neudorf (II, 6a–15); top right: Görau (III, 16a–26b); and bottom right: Wallersberg (IV, 27a–M5). Number–letter combinations in each plot (left) stand for ^{14}C dates listed in Table 2. Dashed lines represent the boundaries of colluvial deposits. Bar length is normalized to 100%, indicating the composition ratio of wood types. Note that the position of the bars along the *x*-axis varies according to the underlying ^{14}C dates (black boxplots; 2σ ranges without distributions) to make general trends of vegetation composition visible. In case of one ^{14}C date per feature/deposit, we placed the bar as centrally as (graphically) possible above the boxplot; in case of two or more ^{14}C dates, the bar is positioned along the full range of ^{14}C dates. N means the number of charcoal samples analysed in terms of the wood type. At Wallersberg (IV), the age information on M4 and M5 is derived from OSL analysis due to the lack of charcoal for ^{14}C dating. Graphics: T. Seregély and K. Kothieringer.

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ORCID

Katja Kothieringer http://orcid.org/0000-0001-7520-5754
Raphael Steup https://orcid.org/0000-0001-8442-5951
Karsten Lambers http://orcid.org/0000-0001-6432-0925

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