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The well-preserved Late Neolithic dolmen burial of Oberbipp, Switzerland. Construction, use, and post-depositional processes

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A R T I C L E I N F O

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A B S T R A C T

Excavation of the Late Neolithic dolmen of Oberbipp BE, Steingasse in the Swiss Central Plateau provided a unique opportunity for a comprehensive study of the archaeological and anthropological evidence. In multidisciplinary studies, we investigated the processes at work during construction, use, and abandonment of the megalithic structure, as well as the dietary habits, subsistence strategy, and possible mobility of the Neolithic population. Archaeological methods included micromorphology, archaeobiology, typology, use-wear analysis, and geology. The anthropological investigation was complemented by an analysis of stable isotope ratios and palaeogenetics. Local topography and the cover of alluvial sediments ensured an extraordinary conservation of the monument. It allowed the preservation of the human remains of at least 42 individuals of both sexes and all ages. The observation of the sedimentary and post-depositional processes, supplemented by an extensive series of radiocarbon dates, allowed us to reconstruct the history of the dolmen in its environment and the definition of at least two deposition phases. We found genetic evidence of lactase intolerance, a local population with a mixed ancestry of early Anatolian farmers and Western hunter-gatherers, and a crop-based diet. Sparse remains of a nearby Late Neolithic settlement sustain the interpretation that this is the burial site of a local farming community. Evidence of higher mobility of females and kinship over three generations solely in the paternal line suggests a virilocal community. Bone-altering pathologies support the assumption of a caring society.

1. Introduction

1.1. Context

Prehistoric funerary monuments constructed of massive stone blocks, known as megalithic dolmen structures (from the Breton words *dol-min* for stone table), emerged around 4500 BCE in northwestern France (Sánchez-Quinto et al., 2019). Cultural exchange and maritime mobility spread the concept of these megalithic constructions from the Atlantic coast along waterways to the east, reaching central Europe and the Swiss Central Plateau over a millennium later (Schulz Paulsson, 2019). Dolmen as burial sites were excavated and studied as early as the 19th century (Bertrand, 1864; de Bonstetten, 1865). While new megalithic tombs with human remains are still being discovered and studied

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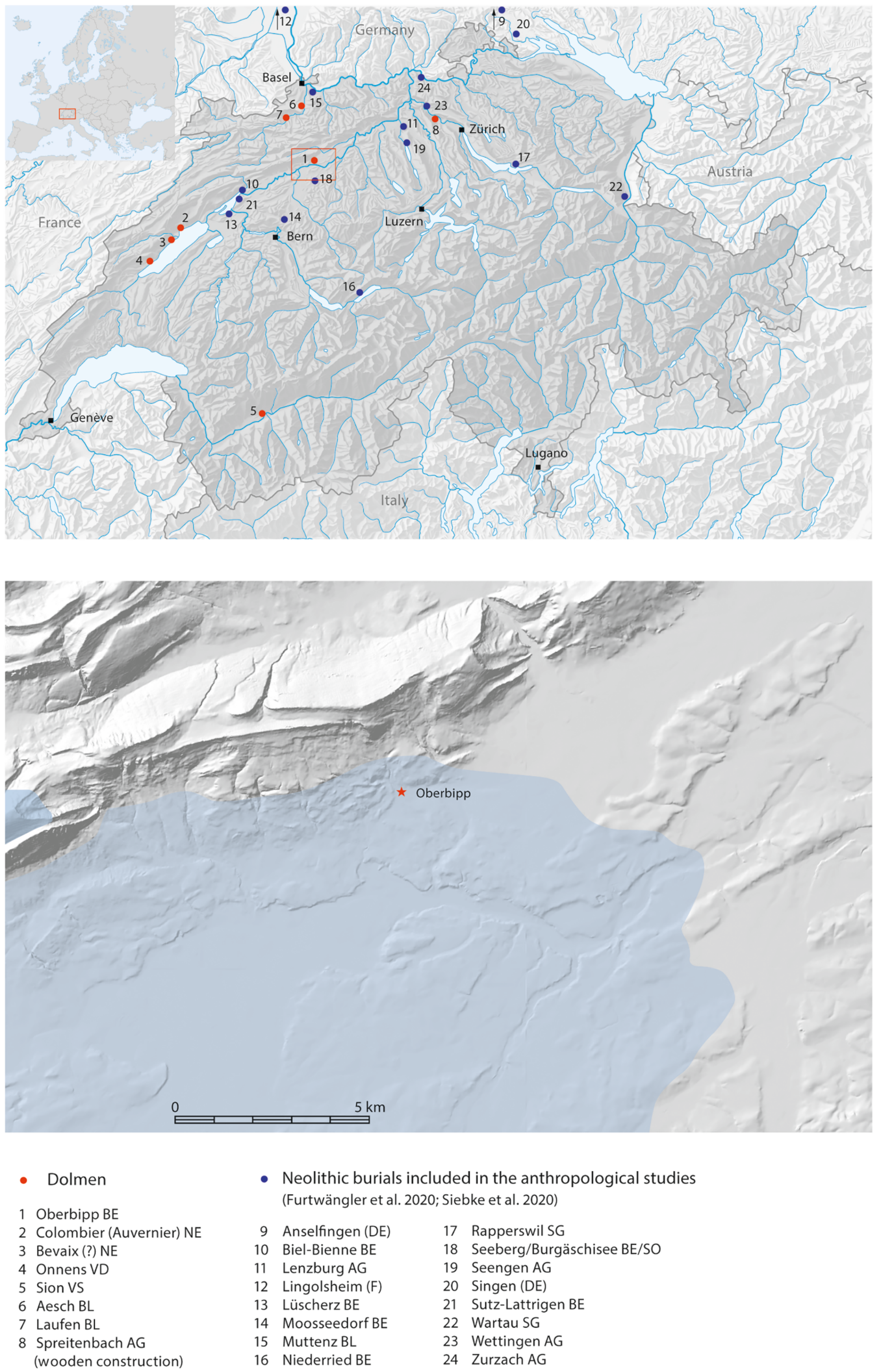

Fig. 1. Dolmen burials of Switzerland and additional sites included in the study. Light blue: extension of the Last Glacial Maximum (LGM; Bini et al., 2009).

in parts of Europe (e.g. Alt et al., 2016; Aranda Jiménez et al., 2020; Beckett, 2011; Blank et al., 2021; Fernández-Crespo and de-la-Rúa, 2015; Sánchez-Quinto et al., 2019), such finds are rare in the densely populated and built-up Swiss Central Plateau (western Central Europe). With the ongoing progress in biochemical and palaeogenetic methods, human remains offer a window to study the little known funerary biographies of the regional Neolithic population in context with the better-known archaeological evidence of settlements. Recent research in Spain (Fernández-Crespo and de-la-Rúa, 2015; Alt et al., 2016; Aranda Jiménez et al., 2020), Scandinavia (Blank et al., 2021) or the British Isles (Sánchez-Quinto et al., 2019) combines archaeological and bio-archaeological data. In this context, our data of the Oberbipp dolmen represents a rare opportunity for a comprehensive analysis of the construction, use, and re-use of a megalithic funerary monument in Central Europe. Using a multidisciplinary approach, we aimed to contribute to studies on social dynamics, mobility patterns, and the evolution of Neolithic burial practices on a broader European scale.

Fig. 2. The profiles during excavation show an alternation between fine-grained (loamy) and coarse (gravelly) deposits going back to low and high fluvial dynamics.

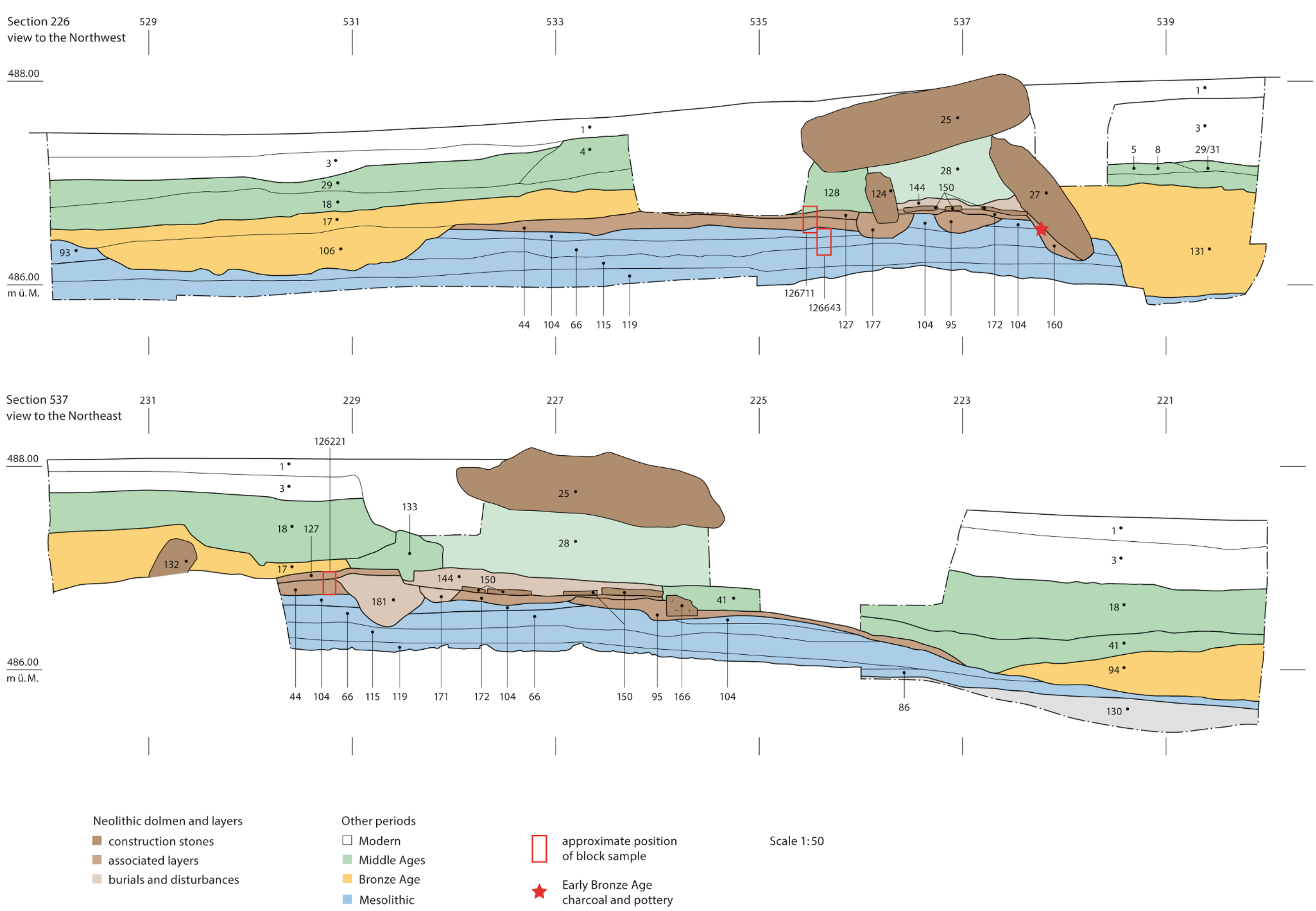

Fig. 3. Sections of the Dolmen with the location of the analysed soil columns.

1.2. Discovery and excavation

In 2011, the Archaeological Service of the canton of Bern discovered a Late Neolithic dolmen in Oberbipp (northwestern Switzerland, Fig. 1; Ramstein, 2014). Covered by the sediments of the nearby stream, the megalithic burial site survived until discovery with only a minor part of the capstone visible. The excavation of the megalithic monument took place from February to December 2012 and comprised 140 m^2. A team of anthropologists and archaeologists managed documentation and on-site sampling. Three-dimensional documentation with laser and

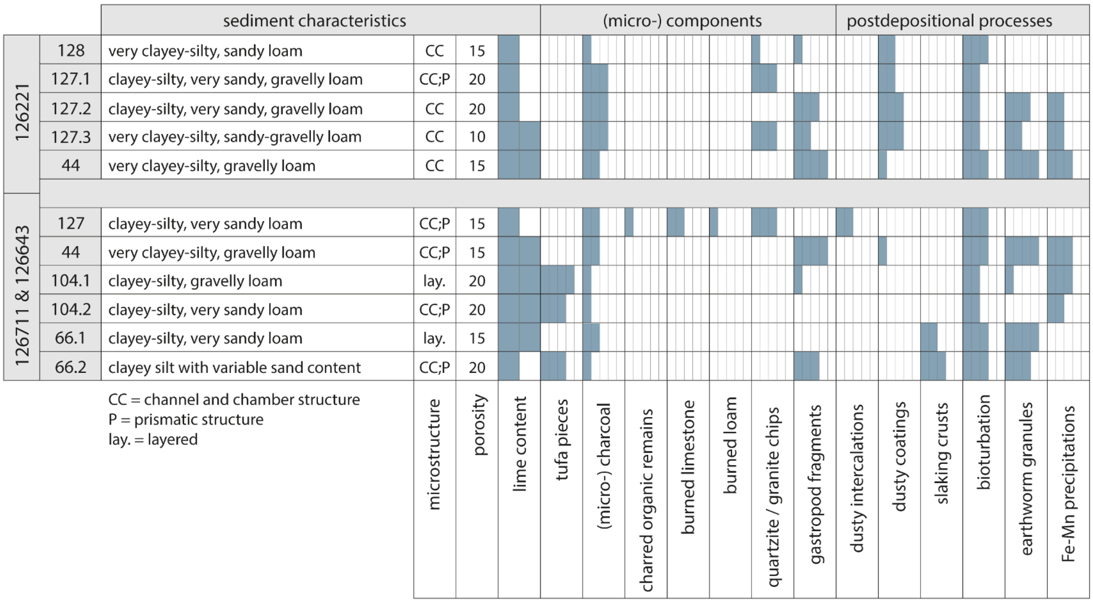

Fig. 4. Characteristics of the investigated layers and semi-quantitative results of the micromorphological analysis regarding (micro-)components and post-depositional processes (for further information, see annexe 1). No bar = absent; one bar = single / very week; two bars = few / week; three bars = frequent / clear; four bars = numerous / strong; five bars = dominant / heavy.

Fig. 5. The orientation of the buried with the head/torso in the southeast, legs in the northwest was recognisable in the lower, undisturbed layers like here in spit 11.

structured light scanners (Siebke et al., 2018), supported by conventional photography and drawing, allowed state-of-the-art documentation of the dolmen construction and skeletal remains. Excavation of the dolmen led to intensified monitoring of construction sites in the vicinity and documentation of several nearby spots with radiocarbon-dated traces of a Neolithic and early Bronze Age occupation, limited to a few square metres because of poor conservation and size of the construction projects (Ramstein et al. 2020, 146–147).

1.3. Topography and geology

Oberbipp lies at the southern foot of the Jura Mountains, on the two-kilometre-wide alluvial fan of the local stream, called "Dorfbach", formed during the Late Glacial and Holocene (Ramstein et al., 2020, 97). This stream cuts through zones of Jurassic limestone and moraine deposits. On the investigation site, fluvial erosion gullies several metres wide and filled with coarse limestone gravel alternate with fine, loamy overbank deposits from the lateral zone of the stream (Fig. 2). The dolmen stood on one of these fine-grained alluvial layers at the edge of the historic village, Oberbipp. The latter is situated around the church (8th century) and in the area of a Roman villa (2nd/3rd century CE).

1.4. Aim of the study

In this study, we focused on human and natural impact during construction, use, and abandonment of the dolmen site. We also aimed to understand the duration of use and the funeral practice, dietary habits, subsistence strategy, health conditions, kinship, and possible mobility of the Late Neolithic population buried here.

2. Materials and methods

2.1. Archaeology

The post-excavation analysis included comparative archaeology, micromorphology, archaeobiology, and geology (Ramstein et al., 2020). We integrated the study of the archaeological finds, including the Mesolithic, Bronze Age and Medieval material found near the dolmen. Formal comparison and typological dating of pottery and other post-Neolithic finds supplemented the analysis of the potential grave goods: chipped stone tools and pendants made from animal teeth, bones, stone, and mollusc shells. The raw material of the chipped stone tools, found within the dolmen and its close vicinity, was determined through identification of the sedimentary microfacies as described by Affolter (2002) and complemented by a lithic microscopic use-wear analysis following the methods of Finlayson and Mithen (1997) and Grace (1989).

2.2. Soil micromorphology and geology

Our first geoarchaeological and geological evaluation occurred on-site during the excavation. The micromorphological analysis of three block samples from the well-preserved western side of the Dolmen (FK 126221, 126643, 126711; Fig. 3/annexe 1) with eleven soil thin-sections followed the method described by Goldberg and Macphail (2006). The optical evaluation by binocular and polarisation microscope regarding the texture, fabric, and composition of the deposits according to the guidelines for micromorphological examination of archaeological sediments (Bullock et al., 1985; Stoops, 2003) focussed on the landscape evolution, the formation of the archaeological layers and structures, and post-depositional processes. We recorded the features semi-

Lab-Code	y BP	±1 σ	Sample	Position	Slip	Material	Description/ Remarks	δ ¹³C ‰	C %	C:N ratio	Collagen yield %	cal age (1σ) from	cal age (1σ) to	cal age (2σ) from	cal age (2σ) to
Radiocarbon dates used in the archaeological interpretation of the dolmen and surrounding layers															
Pre-dolmen fluvial fine sediment: Mesolithic															
BE-10930.1.1	10255	28	127346	173		charcoal	charcoal spot beneath 119					-10048	-9889	-10143	-9872
BE-11958.1.1*	10193	179	157026	173		charcoal						-10483	-9453	-10634	-9320
BE-10927.1.1*	9855	105	124850	93/115		charcoal	Layers with mesolithic chipped stone artefacts					-9651	-9225	-9792	-8929
ETH-47939	9691	42	121880	113		charcoal		-28.4				-9248	-8948	-9270	-8858
ETH-56363	9486	34	121862	66		charcoal	Ancient topsoil	-26.6		106.3		-9106	-8713	-9118	-8634
BE-10925.1.1	9521	27	124647	66		charcoal						-9113	-8767	-9120	-8742
ETH-47938	1119	29	121860	66		charcoal	disturbance of hydraulic excavator, discarded	-29.9				894	978	775	996
Pre-dolmen sediment and structures: Neolithic															
BE-10926.1.1	5576	23	124820	140		charcoal	post-hole: pre-dolmen?					-4444	-4360	-4449	-4352
BE-7024.1.1	4442	18	126402	44		charcoal	topsoil, pre-dolmen; contains mesolithic chipped stone artefacts					-3280	-3023	-3326	-3011
BE-7021.1.1	4483	18	124809	44		charcoal						-3327	-3099	-3337	-3091
BE-11959.1.1*	4405	106	157027	172		charcoal						-3321	-2910	-3483	-2779
BE-7023.1.1	4918	18	127345	172		charcoal	sediment beneath pavement					-3702	-3648	-3756	-3641
BE-10603.1.1	4754	22	155995	172		charcoal						-3625	-3523	-3632	-3384
Construction pits of the dolmen															
BE-7025.1.1	5331	35	127344	178		charcoal	western pit					-4240	-4059	-4316	-4048
ETH-56366*	3651	91	127359	160		charcoal	eastern jambstone pit	-25.1		-		-2187	-1897	-2290	-1750
Disturbed parts of the filling in the burial chamber															
ETH-48723	1282	31	126163	144	3–6	charcoal	disturbance near entrance	-26.0		126.0		677	772	662	821
BE-9197.1.1	4218	23	125112	28	4	bone	Sus domesticus, Ulna		34.0	3.2	7.2	-2890	-2775	-2897	-2700
BE-9200.1.1	4174	23	125112	28	4	bone	Vulpes vulpes, Tibia		31.9	3.2	10.2	-2874	-2698	-2882	-2666
Charcoal from sediment between burials of the lowest layers															
BE-10602.1.1	4429	50	155994	144	11–12	charcoal						-3315	-2930	-3333	-2917
ETH-48724	4662	37	127181	144	11–12	charcoal		-15.3		68.0		-3510	-3370	-3522	-3363
ETH-48725	4775	35	127182	144	11–12	charcoal		-25.4		202.3		-3630	-3527	-3639	-3382
Animal burrows distrubing the dolmen															
BE-10604.1.1	4395	41	155996	171		charcoal						-3086	-2923	-3318	-2905
BE-9199.1.1	4154	23	126429	171		bone	Meles meles, Mandibula		35.4	3.2	12.1	-2867	-2672	-2874	-2630
BE-9203.1.1	4129	23	127326	180		bone	Meles meles, Humerus		33.6	3.2	8.7	-2852	-2629	-2867	-2581
BE-10928.1.1	4099	22	127341	180		charcoal						-2837	-2579	-2854	-2504
Bronze Age structures/pits															
BE-10601.1.1	3362	32	155993	105/98		charcoal	Early Bronze Age; pottery, bones					-1732	-1565	-1739	-1537
BE-10600.1.1	3006	21	155992	117/116		charcoal						-1283	-1210	-1377	-1130
ETH-56365	3017	26	123479	117/57		charcoal	Late Bronze Age; pottery, bones, chipped stone artefacts	-28.1		109.1		-1369	-1217	-1385	-1130
BE-10599.1.1	2937	22	155991	117/63		charcoal						-1207	-1112	-1218	-1049
ETH-47940	2953	31	123483	117/63		charcoal		-25.7				-1220	-1115	-1260	-1050
Layers and clearance cairns (128, 133) with 13th-century pottery and roman tiles															
BE-10598.1.1*	838	212	155990	7		charcoal	charcoal layer at dolmen entrance					993	1390	686	1456
BE-10943.1.1*	672	64	123079	7		charcoal						1277	1393	1230	1409
BE-9195.1.1	754	22	124625	31		bone	Capra hircus/ovies aries, Radius		28.4	3.1	4.7	1261	1283	1227	1286
ETH-56364	983	25	123467	41		charcoal	layer contains many roman tiles	-27.8		32.9		1024	1148	995	1158
BE-10597.1.1	792	20	155989	41/110		charcoal						1229	1267	1222	1274
BE-9196.1.1	4096	23	124561	128		bone	Meles meles, Ulna		24.1	3.2	4.5	-2836	-2578	-2855	-2500
BE-7022.1.1	3594	18	126250	133		charcoal						-2010	-1900	-2020	-1889
BE-9204.1.1	1241	22	123250	133		bone	Bos taurus, Metapodium		31.5	3.1	6.8	704	826	681	879
BE-9198.1.1	814	22	123250	133		bone	Bos taurus, Scapula		36.6	3.2	9.4	1223	1261	1181	1274
BE-9202.1.1	751	22	123250	133		bone	Capra hircus/ovies aries, Mandibula		35.2	3.2	8.2	1264	1283	1228	1287
Radiocarbon dates from sites in close vicinity of the dolmen															
Oberbipp, Bachweg 11															
BE-10596.1.1	4638	22	154330	-		charcoal	ancient topsoil?					-3494	-3366	-3511	-3360
Oberbipp, Beundenstrasse															
BE-11412.1.1	4759	22	139879	9		charcoal	ancient topsoil?					-3625	-3525	-3633	-3385
Oberbipp, Mettlenstrasse 4															
ETH-63205	4480	31	136120	4		charcoal		-28.6		218.0		-3329	-3096	-3340	-3029
ETH-65147	4460	28	139887	4		charcoal		-29.0		140.2		-3323	-3029	-3335	-3020
ETH-65146	4557	28	139886	5		charcoal	layer with pottery, chipped stone artefact, bones, burnt stones	-23.7		137.5		-3367	-3125	-3483	-3102
ETH-65145	4660	29	139865	6		charcoal		-26.9		200.2		-3507	-3370	-3515	-3367
Oberbipp, Weihergasse 21															
BE-11411.1.1	3395	21	148561	6		charcoal	ancient topsoil?					-1735	-1631	-1742	-1621

Fig. 6. Radiocarbon dates supporting the archaeological interpretation. Calibrated with Oxcal v.4.4 (Bronk Ramsey, 2009); IntCal20 (Reimer et al., 2020). **small sample, gas measurement.*

quantitatively (e.g. dusty coatings, earthworm granules, amount of microcharcoals; Fig. 4). Petrographic analysis and provenance studies of the construction stones completed the investigation.

2.3. Archaeobotany and archaeozoology

For the archaeobiological studies, we collected the sediment between the human bones with aspirators and sieved it with the wash-over method (Hosch and Zibulski, 2003), using mesh sizes of 8, 2 and 0.35 mm. To reduce the impact of post-use perturbations, we only included samples from the lower burial layers in undisturbed areas and focused on the botanical and animal remains of the 8 and 2 mm fractions (spits 7–12; e.g. Fig. 5.). Thus, 27 samples (399 of 888 L of collected sediment) were processed. Each litre of the sieved sediment contained 12 ,000 to 45 ,000 minuscule bone fragments, most of them human. We extracted the determinable animal bones and plants (except charcoal) for analysis.

2.4. Anthropology and molecular genetics

We assumed all human bones belonged to the use period or periods of the monument, despite the fragmentation and dislocation of the human remains within the burial chamber. There were no traces of out-of-context deposition of human remains.

The anthropological study estimated the minimum number of individuals (MNI) based on the most frequent skeletal element (right femora) comparable to Mack et al. (2016) and Osterholtz et al. (2014). Siebke et al. (2019) studied the identifiable individuals based on the following methods: age at death (Scheuer and Black, 2004), body height (Martin, 1914; Pearson, 1899), pathologies (Steckel et al., 2011; Mann and Hunt, 2005), and sex (Sjøvold, 1988). The latter was being verified through DNA analysis if possible. These morphological results formed the basis for the biochemical analyses. To prevent redundancies in sampling, we exclusively used the right side femora (n = 32) and petrous bones *(pars petrosa;* n = 23). Those served as samples for radiocarbon dating (Szidat et al., 2017), the latter also for palaeogenetic studies (following Gamba et al., 2014) and stable isotope analysis.

With the collagen extraction following Ambrose (1990), DeNiro (1985), Longin (1971) and the determination of stable isotope ratios (d13C, d15N, d34S; Katzenberg, 2008; Nehlich, 2015) we attempted the reconstruction of dietary habits, subsistence, and potential mobility. Analysis of 60 samples of Neolithic animal bones from Oberbipp and Twann, a contemporaneous Neolithic settlement 42 km to the southwest, served as a benchmark (Siebke et al., 2020). Aside from sex determination, kinship, and population-genetic studies concerning the geographical origin, the palaeogenetic analysis focused on pathogen DNA (Furtwängler et al., 2020; Key et al., 2020). A comparative analysis of Neolithic and Early Bronze Age graves in Switzerland and adjacent regions of France and Germany supplemented the study.

2.5. Radiocarbon dating

Three laboratories performed the radiocarbon dating of the right human femora and petrous bones (Steuri et al., 2019). This approach allowed verification and validation of the individual dates. Radiocarbon dates of charcoal and animal bones supplemented the archaeological interpretation (Fig. 6). For calibration, we used Oxcal v.4.4 (Bronk Ramsey, 2009), based on IntCal20 (Reimer et al., 2020). For the verification of different burial phases, several dates were recalibrated, divided into two phases using OxCal v.4.4.4 (Bronk Ramsey, 2009), and summarised, using the kernel-density estimation (KDE) plot, as suggested by Bronk Ramsey (2017). The frequentist method KDE can be applied to a series of related dates to characterise the overall age range and distribution of dated events while removing much of the high-frequency variability that makes sum distributions tricky to interpret (Loftus et al., 2019). Sum distribution often exhibits sharp drops and rises associated with features in the calibration curve and an excessive spread beyond the range from which the dates have been sampled, especially where there are plateaus (Bronk Ramsey, 2017).

3. Results

3.1. Site occupation

The underlying fluvial fine sediments of the site show a weak soil formation and traces of a first occupation in the early Mesolithic period. A series of over two hundred chipped stone artefacts, a topsoil layer (66) rich in micro charcoal, and radiocarbon dates attest to human activities in the younger Preboreal (ca. 9100–8700 calBC; Fig. 6/annexe 1). Later flooding events (during the Late Atlantic period?) were succeeded by a less dynamic phase with reduced sedimentation and development of a humiferous topsoil (44) during the Late Neolithic (3350–3000 calBC, Ramstein et al., 2020, 178; fig. 116/annexe 1).

While absolute dating of the dolmen construction remains difficult, 29 radiocarbon dates of femora fall into the period of 3350 to 2950 calBC, where a plateau in the calibration curve (Reimer et al., 2020) prevents more accurate dating without applying informative priors like kinship constraints. However, three scattered femora from the uppermost burial layers date 2900 to 2650 calBC (Steuri et al., 2019). To test the validity of the presence of at least two phases of burial activity, the radiocarbon data of these femora were recalibrated using the current calibration curve (IntCal 20, Reimer et al., 2020) and divided into two phases using OxCal v.4.4.4 (Bronk Ramsey, 2009). Within each one, we summarised the dates using the kernel-density estimation (KDE) plot, as suggested by Bronk Ramsey (2017). The resulting model (annexe 2) further supports at least two phases of burial activity within the dated femora ($A_{model} = 77$; the quality factor of the model agreement index should be over 60 to be significant). Three individual dates from the older phase show slightly poor agreement (A around 25–50), but the other dated samples from the same bone fit well with the model ($A > 95$).

A pottery fragment and charcoal from the construction pit of the eastern jambstone belong to the Early Bronze Age (2200–1900 calBC). Finds and radiocarbon dates from several ditches near the dolmen evidence occupation of the site throughout the Bronze Age. Tiles, grey earthenware, and several radiocarbon dates from the disturbed upper burial layers and the sediments covering the Neolithic remains show a human presence in the Roman era and Early Middle Ages, with intensified activities in the 13th century.

3.2. The monument

The construction pits of the dolmen cut into the Neolithic and Mesolithic layers. They served as foundations for four gneiss slabs, the orthostats, wedged with limestone blocks and covered by the capstone. The latter, a roughly trapezoidal gneiss slab with smoothened lateral sides, weighed approximately eight tonnes before its partial destruction. Its granitic/granodioritic lithology indicates a provenance from the external Alpine massifs (Aar or Mt. Blanc Massif). A recent (illegal) attempt to dismantle the boulder, testified by modern drill holes, resulted in the breaking-off of several fragments, some retrieved in the vicinity. Two jambstones of coarser-grained gneiss flanked the monument on the valley-side. All these stones except the southern orthostat tilted to the southwest.

Uphill, in the northwest, the rear of the almost rectangular burial chamber (2.0 × 1.4 × 0.7 m) was disturbed, the original closing stone no longer in place. Downhill, in the southeast, a poorly preserved block of calcareous tuff served as a threshold or entrance slab. The neat pavement of the chamber comprised trimmed slabs of local sand- and limestone. Except for the tuff block and the pavement, the construction stones were erratic boulders of Alpine origin. We recovered several Alpine gneiss and limestone blocks around the dolmen without a clear connection to the monument. One 1.5 m tall gneiss boulder lay overturned next to its foundation pit. In an erosion gully to the northeast, we found another gneiss (at least 1.0 × 0.6 × 0.2 m, stuck in the profile) and a local oolitic limestone block. In addition, the current leaseholder of the plot had removed and damaged a slab of Alpine marly limestone with a hydraulic excavator before the archaeological investigation.

The micromorphological sediment analysis showed two distinct construction phases (Ramstein et al., 2020, 114–117; annexe 1). Evidence for compaction by trampling and deposits of sharp-edged gneiss fragments marked the older one (fig. 4, 127.3). An accumulation of 3 cm of clay-rich sediment covered this horizon (127.2) and separated it from the second construction phase, marked by angular chips of local oolitic and Alpine marly limestone (127.1; annexe 1).

3.3. The burials

Laid to rest in a supine position, the heads of the individuals pointed towards the wider narrow side of the burial chamber in the southeast, the feet towards the shortest side and the natural slope in the northwest

Fig. 7. Finds from the burial chamber: arrowheads and knives (siliceous raw materials), dogtooth pendants, fossil mollusc, seashell, stone and bone beads, pig teeth.

(Fig. 5). While several skeletal elements remained in anatomical position, we found no complete skeleton. On the other hand, we observed at least six superimposed deposition levels. Fragmented bones dominated the upper burial layers, but taphonomic alterations had affected all bone surfaces. The anthropological study included over 2000 bone fragments representing all human body parts. Analysis of the right femora allowed determining a minimum number of 42 individuals: a neonate, two infants (1–6 yrs), eight children (7–13 yrs), seven adolescents (14–20 yrs), and twenty-four adults (+20 yrs). The fusion of cranial sutures on skull fragments suggested individuals of age at death above 40 or even 60 years (Siebke et al., 2019). The palaeogenetic analysis confirmed both sexes and at least twelve males and nine females. Some specimens did not provide results due to degradation (Furtwängler et al., 2018). Three complete femora allowed calculation of body heights between 154 and 157 cm (undetermined sex).

Caries intensity in the 726 investigated teeth was 8.3%. Palaeopathological alterations like traumas, inflammatory reactions, and age-related changes included healed fractures and a case of severe, chronic inflammation of the femur (osteomyelitis) with cloaca (Siebke et al., 2019).

Quality control left 18 samples for mass spectrometry of the stable isotopes carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) and 16 for sulphur ($^{34}S/^{32}S$) for the evaluation of dietary habits, subsistence and potential mobility.

First-grade kinship tied together three generations. This cluster comprised two half-brothers, their father and a son each. A pair of full brothers were the only other evidence of kinship. Related females were absent. Samples of 17 individuals showed a lack of lactase persistence. Phenotypic traits included a high probability of a light complexion and, in six cases, a light eye colour. The modelling of ancestry components revealed a mixture of genetic components found in Anatolian Neolithic farmers (60–90%) and Western European hunter-gatherers (10–40%; Furtwängler et al., 2020). In one sample, the screening for pathogen DNA showed a match with bacteria of Salmonella enterica spp. enterica (Key et al., 2020).

3.4. Associated artefacts

The finds from the burial chamber (Fig. 7) comprise eleven chipped stone tools (nine arrowheads, two knives), four pendants crafted from dog canines, two pig canines, two limestone disc-beads, a fragment of a belemnite probably used as a bead, and a tubular bead made from a segment of a bird bone. A pierced seashell *(Stramonita haemastoma)* served as another pendant, and a fossil mollusc *(Tympanotonos margaritaceus)* might belong in a similar context (Ramstein et al., 2020, 162). The chipped stone tools consist of regional silex, except for a red arrowhead made from radiolarite originating in the Rhine valley in southern Germany. A knife blade displays wear marks and a few arrowheads possible residues of their mounting. Contrary to those from the burial chamber, the tip of one of the two arrowheads found beside the dolmen shows impact damage typical of projectile point use (Ramstein et al., 2020, 154–159).

3.5. Archaeozoology and archaeobotany

While most of the minuscule bone fragments in the soil samples from the burial chamber were human, they contained 1406 faunal bones and bone fragments (Ramstein et al., 2020, 170–178). Because of the high percentage of small animals like reptiles (64%), small mammals (23%) and amphibians (9%), 70% of the bones were intact. With 866 remains (62%), blindworms *(Anguis fragiles)* were most frequent. Big mammals (3%) and birds (1%) were rare.

From 88 botanical remains retrieved from the samples, 36 could be determined. Most common were Cerealia, represented by 24 specimens (three identified as *Triticum dicoccon*). The rest were wild plants, including two hazelnut shells *(Corylus avellana)* and four elder seeds (*Sambucus* sp.).

4. Discussion

4.1. Limitations of the study

Despite the exceptional conservation of the Oberbipp dolmen, certain limitations apply to our interpretations. Several zones of the burial chamber show post-occupational perturbation by animals and humans. A few radiocarbon dates, fragments of Roman tiles, iron, and slag commingled with fragmented and dislocated bones in the uppermost burial layers confirm post-depositional disturbances. Grave goods could not be associated with particular individuals in the close-packed collective burial. Taphonomic circumstances led to suboptimal conservation of the biomolecules, such as collagen and aDNA. However, our exclusion of low-quality samples allowed results despite the reduced sample size. As experienced in other contexts and regions (e.g. Meadows et al., 2020, Blank et al., 2020, McLaughlin et al., 2016), the plateau of the calibration curve for radiocarbon dates in the last third of the fourth millennium BC and lack of informative priors–like stratigraphic or kinship constraints–hindered a more differentiated dating of the burials.

4.2. Landscape history

During the Last Glacial Maximum (LGM), glacial sediments (moraine) accumulated on the Swiss Central Plateau and were subsequently covered

Fig. 8. The dolmen after removal of the burials. The regular pavement shows attention to construction details.

by fluvioglacial and local loess deposits (Veit et al., 2017). During its retreat, the merged Rhone/Aare Glacier left various Alpine erratic blocks in the region. This local abundance raises the question of whether it influenced the location choice for the monument only about one kilometre from the maximum extent of the LGM glacier tongue (Fig. 1). To the northeast of this line, similar boulders are lacking. However, the availability of water and fertile soils certainly played a crucial role in the choice of settlement areas. Radiocarbon dates from an ancient topsoil layer and the excavation of 9 m^2 of a site with pottery and chipped stone artefacts suggest contemporaneous human activities, possibly a late Neolithic settlement less than 250 m to the southeast of the dolmen (Ramstein et al., 2020, 146–147; Fig. 6). In a broader international context, megalithic structures scattered throughout the landscape might be territorial markers, each related to a settlement (Renfrew, 1979). Gebauer (2015) proposed several models, interpreting the location of megalithic tombs at the edges of the domesticated landscape of a community–including clustering of burials and, in several cases, impressive landscape modifications. Thus, the dolmen might mark the boundary between a cultured landscape and the wilderness.

The micromorphological results and bones of small animals from the Oberbipp burial chamber paint the picture of a landscape shaped by the local stream and marked by a frequently humid biotope. However, most small animals may well have intruded after the abandonment of the monument and probably lack any relation to its use and purpose.

While constructed in a morphodynamic stable phase, deep gullies washed out by water surrounded the dolmen later. Late Neolithic human impact by intensified deforestation and agriculture might have caused or increased this change in the fluvial dynamics (Mäckel et al., 2009). Palaeoecological analysis on a sediment core from nearby Lake Burgäschi (Fig. 1,18) confirms increasing fire activity and the first appearance of pollen grains of Cerealia-type and *Plantago lanceolata* around 4550 calBC, marking the onset of agricultural activities in the region (Rey et al., 2017, 579).

Aside from a few Bronze Age pits, we lack indications for site use and landscape development during the Bronze and Iron Age. However, the sediment covering the Neolithic soils and clearance cairns around the monument contained pottery from the 13th century CE, signalling on-site activity. Maps from the late 19th century suggest agricultural exploitation by artificial flooding of the meadows, the traditional regional form of irrigation (Leibundgut and Kohn, 2014). This practice, established in medieval times, led to the significant sediment influx covering the dolmen. Thus, it may well be the reason for its preservation.

4.3. *The regional burial tradition in the late fourth millennium*

While dolmen burials are common in large parts of Europe, in Switzerland only a few of them survived to the present day. Erratic blocks were a common building material, and farmers considered megalithic structures in arable land obstructive. Only topographic locations with heavy fluvial sedimentation allowed monuments to survive, e.g. at the Sion dolmen sites Petit-Chasseur and Don Bosco (Fig. 1; Bocksberger, 1976; Bocksberger, 1978; Gallay and Chaix, 1984; Gallay, 1989; Favre and Mottet, 2011; Mottet, 2019).

The Swiss dolmen, dating from 3500 to 2800 BCE, are complemented by a younger collective burial site, Spreitenbach, Moosweg (Fig. 1). The unique wooden construction dates to the End Neolithic (mid 3rd millennium; Doppler et al., 2012). We included it in the anthropological study because of its proximity, recent discovery, and good bone preservation.

The dolmen of Colombier, Plantées de Rives (Désor, 1876; Gross, 1876) and Onnens, Praz Berthoud (Falquet and Burri-Wyser, 2016) offer the best comparisons to Oberbipp. Also built on the southern slopes of the Jura Mountains, both show the same orientation as the Oberbipp dolmen. Together, the three sites form the group of the Jura-foothill dolmen (Weidmann, 2016). Excavation of Colombier took place in 1876. The dolmen of Onnens, investigated 2000/01, had unfortunately been dismantled in Roman times or the 16th to 18th century (Falquet and Burri-Wyser, 2016, 172–173). The same might apply to the site of Bevaix, Le Bataillard (Leducq et al., 2008, 61–70), although interpreting the documented pits as dolmen foundations remains hypothetical. However, it is striking how their size and orientation correspond with the other three megalithic constructions (Leducq et al., 2008, 63, Fig. 41). From the few monuments in the vicinity, the dolmen of Aesch in northwestern Switzerland showed a similar pavement (Sarasin, 1910).

4.4. *Construction and use of the monument*

Based on the stratigraphic observations, we suggest the following hypothesis for the construction of the Oberbipp dolmen: The Neolithic builders flattened the construction site by removing part of the topsoil. They placed the orthostats into oblong, 0.3 m deep foundation pits and wedged them with blocks of local limestone. A temporary filling of the burial chamber might have enabled them to place the capstone. The neatness of the pavement (Fig. 8) and the absence of foundation pits for the rear and front slabs closing the chamber suggest their installation

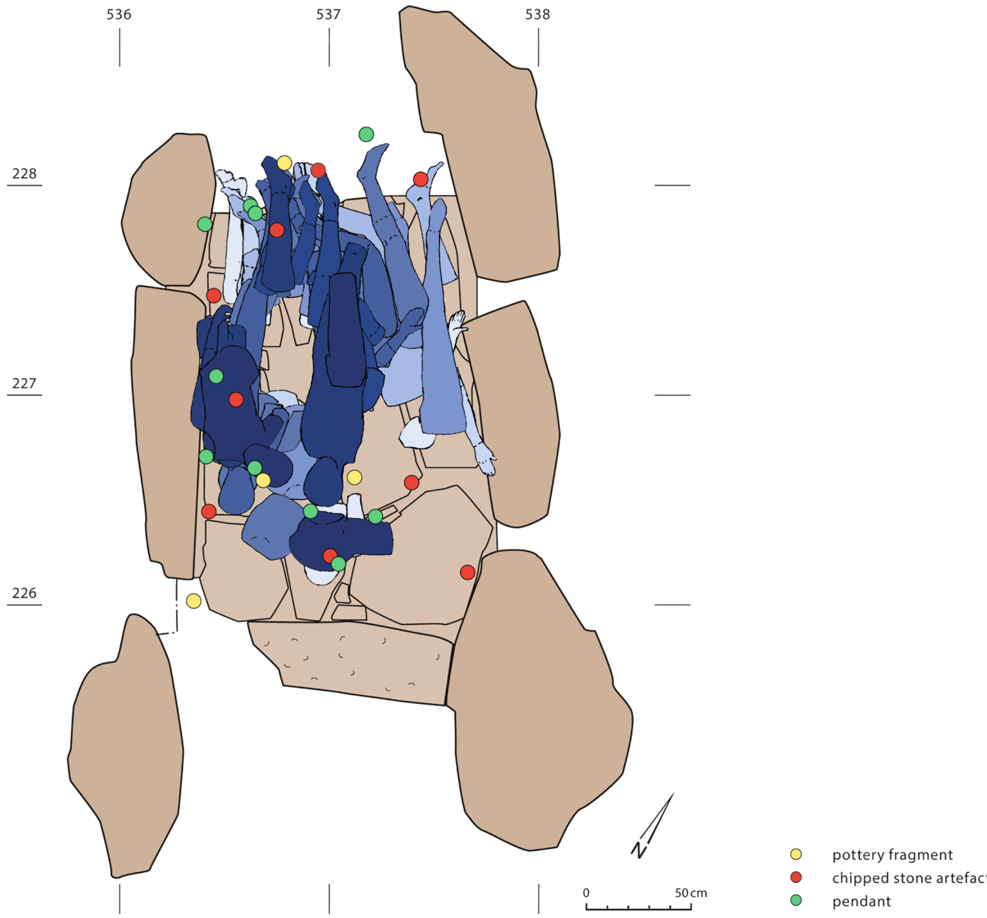

Fig. 9. Superposition of identified body parts in anatomic association and location of the grave goods.

Fig. 10. Calcareous crusts on both the erratic boulder found uphill of the dolmen and in the foundation pit visible in the profile allow the reconstruction of a standing stone.

Fig. 11. The dolmen during excavation surrounded by the medieval clearance cairn. The arrow marks the potential foundation of the marly limestone stela.

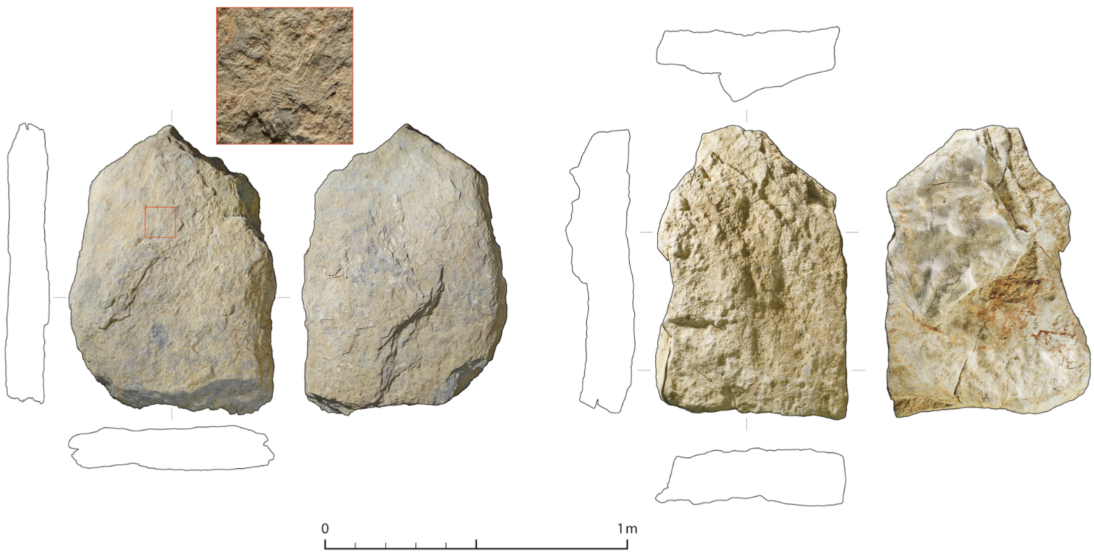

Fig. 12. We found two potential stelae beside the dolmen, one of alpine marly limestone (left, with a detail of the traces of engravings) and one of oolitic limestone (right).

after the capstone. The same applies to the jambstones, a possible later addition (s. below). The execution of the rear of the burial chamber remains hypothetical: Several large pieces of gneiss found on top of the human remains might have been part of a block jammed between the rear orthostats. If so, it did not withstand the pressure of the erosion-induced displacement of the monument. On the valley side, a tuff block closed the dolmen entrance. This well-workable material is abundant in the region. Due to its poor conservation, it remains unclear if a hole or a cutout provided access to the burial chamber. In analogy to the dolmen of Colombier (Fig. 1; Désor, 1876; Gross, 1876), we postulate access through a cutout in the entrance slab instead of a soul hole, as observed north of the Jura Mountains (Schwegler, 2016, 154–156). However, with the Colombier dolmen as the sole example on the Swiss Central Plateau preserved well enough to show the entrance situation, the evidence remains too weak to postulate a regional difference to the northern type with a soul hole or the type Petit-Chasseur with side entrance common in the Alpine Valleys (Schwegler, 2016, 204).

Lacking association of the artefacts from the burial chamber with individuals, their abundance, quality, and dating nevertheless allows us to interpret them as grave goods. The dog-canine pendants, shells, and beads likely served as personal ornaments. Wear marks on a knife suggest its use in harvesting. Several arrowheads show possible residuals from mounting and traces of repair work. One, found beside the dolmen, shows impact damage of the tip.

Despite the underrepresentation of small children, the presence of both sexes, with slightly more males than females, all age groups, and several family ties among the 42 deceased suggest the dolmen served as a collective burial site for a local community. Similar constellations appear in other European Neolithic collective burials (Meyer and Alt, 2012; Fernández-Crespo and de-la-Rúa, 2015, Papathanasiou, 2005). With several superimposed layers of associated skeletal elements (Fig. 9), it seems unlikely that they represent a single funeral event. Radiocarbon dates (Steuri et al., 2019) and disjointed body parts in anatomical connection speak for the re-use of the dolmen during decades or even centuries. The well-documented dolmen MXII of Sion, Petit-Chasseur, is an example showing rearrangement of the bones to gain room for new burials (Fig. 1; Favre and Mottet, 2011, 47–65). Displaced skulls indicate a similar situation for Oberbipp. Relocated body parts in an anatomic connection support the theory that this human-driven shifting happened during the decomposition process and was not due to the secondary burial of fleshed bones.

The rarity of small children might be caused by taphonomic alterations of their smaller and fragile immature bones (Chamberlain, 2006; Manifold, 2015). Therefore, environmental influences like changing humidity, animal activity, and human disturbances must be considered (Siebke et al., 2019). Disparate burial customs for newborn and young children are another possible explanation (Watermann and Thomas, 2011).

Radiocarbon dates of the human bones show two distinct periods of deposition. The plateau of the calibration curve prevents precise dating. Since multiple burial sequences could have occurred over the identified time spans, we cannot exclude that we failed to observe all burial phases. Thus, it remains uncertain during which specific time spans the dolmen was in use. Both a continuous use of the site and several separate use periods seem credible. Nevertheless, the typology of the finds associated

Fig. 13. Central disturbance (arrow) with missing pavement slab (right). The upper burial layers contained few bones in anatomic association, and on both ends of the burial chamber, commingled bones testify to disturbances.

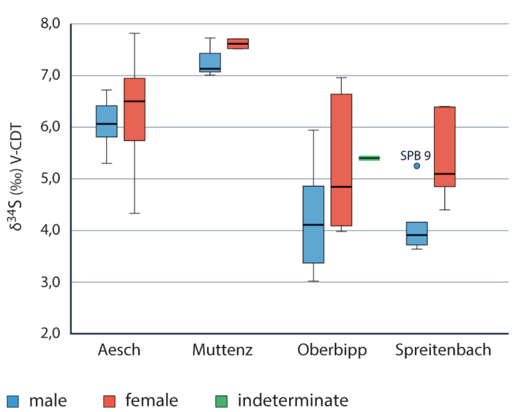

Fig. 14. $\delta^{34}S$ values in comparison with other Swiss Neolithic burials.

with the burials fit into the last third of the fourth/beginning of the third millennium BCE on the Swiss Central Plateau. They also display similarities with grave goods discovered in the context of other regional megalithic funerary structures like Aesch in northwestern Switzerland (Schwegler, 2016), Santoche in eastern France (Pétrequin and Piningre, 1976), or Schwörstadt in southern Germany (Löhlein, 2011).

An Early Bronze Age radiocarbon date (charcoal) from the construction pit of the eastern jambstone of Oberbipp and an associated pottery sherd suggest manipulation of the dolmen as late as 2000 BCE. The clay of the sherd seems to be identical to fragments of an Early Bronze Age pot found in the disturbed upper layers of the burial. In the absence of dated, contemporary human bones, it remains unclear if these finds attest to a Bronze Age manipulation of the site or even an undetected burial phase. Early Bronze Age use and modifications of Neolithic megalithic structures were recorded at the Swiss dolmen sites of Sion and Colombier (Fig. 1; Bocksberger, 1976; Bocksberger, 1978; Gallay and Chaix, 1984; Gallay, 1989; Favre and Mottet, 2011; Gross, 1876) or the eastern French dolmen of Aillevans 1 and Santoche (Pétrequin and Piningre, 1976; Pétrequin, 1985). In the European context, Wollentz (2012) shows the deposition of skeletal elements for the megalithic passage grave from Mysinge (Sweden) during four different phases between 3500 and 1000 BCE by using 34 radiocarbon dates. At Poulawack cairn (Ireland), dated bone samples indicate periods of use from 3600 to 3350 calBC, around 2000 BCE and between 1600 and 1450 calBC (Beckett, 2011), and for the dolmen of Panoría in Spain, radiocarbon dates of human remains show two phases of mortuary activity in the Late Neolithic and Early Bronze Age (Aranda Jiménez et al., 2020).

4.5. *Standing stones and further monuments*

At least two gneiss boulders belonged to monuments outside of the excavated area or served other purposes. In the case of a 1.5 m tall block found next to its foundation pit, calcareous sinter crusts on the stone and the inner surface of the pit allow the reconstruction as a standing stone overturned by the erosive forces of the local stream (Fig. 10). The function of the gneiss in the northeastern profile, embedded in the filling of an erosion gully, remains unclear.

The upper construction layer defined by micromorphology contained chips of Alpine marly limestone and local oolitic limestone (Fig. 4; annex 1). Those might link to the manufacturing of two potential stelae discovered to either side of the dolmen. We recovered the displaced marly limestone slab from the material removed by the leaseholder before archaeological investigation. Several fragments of the same stone linked it to a limestone foundation south of the dolmen entrance (Fig. 11). Minuscule traces of an engraving on its surface support the interpretation as a stela. The oolitic limestone slab from the erosion gully east of the monument features a similar shape and dimensions (Fig. 12).

Standing stones are frequently associated with megalithic funerary structures and can be considered as markers of significant areas or as a manifestation of individual or collective power (Testart, 2012). As a cultural memory, they might also have contributed to the formation and retention of the social community (Furholt and Müller, 2011). An intriguing aspect of standing stones and engraved stelae is their occasional re-use in the construction of funerary monuments throughout Europe, e.g. in Switzerland (Gallay and Chaix, 1984), Italy (Poggiani-Keller et al., 2016) or Spain (Bueno Ramírez et al., 2019, Bueno-Ramirez et al., 2016). The possibly ritual burial of an engraved stela was recently observed in Sion, Don Bosco (Fig. 1, Mottet, 2019).

4.6. Animal activity, human disturbances, erosion, and destruction

Five radiocarbon dates from animal bones found in the disturbed burial layers and animal burrows surrounding the monument fall into the Late/End Neolithic (Fig. 6). They suggest that a badger or a fox burrowed into the dolmen, intruding shortly after the burial period. Considering the perturbations on both ends and in the middle of the chamber, we cannot exclude the relocation of these animal bones in the context of later manipulations. A missing pavement slab beneath the central disturbance pointed out its anthropogenic origin (Fig. 13): An animal hardly would have removed a slab with an estimated weight of 3 to 5 kilos. While reptiles, amphibians, and small mammals used the interior of the dolmen as a refuge, this continuous colonisation occurred likely after the decomposition of the bodies and discontinued human use of the monument.

Fluvial erosion cut deep gullies into the terrain around the dolmen at an undefined later time. While the heavy orthostats withstood the flooding, the monument as a whole tilted sideways because of washout. The increased fluvial activity destroyed most of the strata related to the construction and use of the site. In this light, the lack of traces of a surrounding mound or podium does not disprove their existence.

Middle and Late Bronze Age pottery from the gravel-filled gullies surrounding the dolmen shows the refilling did not take place before the late second millennium. Fragments of Roman tiles, iron, and slag commingled with the dislocated human bones in the upper burial layers prove interferences in the chamber in the Roman period or later. Medieval pottery found in the clearance cairns resting on the Neolithic horizons around the dolmen and in the sediment covering the groove fillings shows the megalithic construction was accessible and visible in the 13th century CE—before fine sediments covered it (Fig. 13). Disturbances in the burial chamber might date to the same period.

4.7. Population and mobility

The comparably high caries intensity suggests a diet rich in carbohydrates. Stable isotope analysis confirms sampled individuals lived on local plants and cereals with a smaller proportion of animal products. The correlation between lower nitrogen values and higher caries intensity evidences a higher intake of carbohydrates for the residents of Oberbipp compared to other Neolithic humans (Siebke et al., 2020). The postulated agricultural subsistence strategy at Oberbipp seems to fit with the geographical location and topography (see detailed discussion in Siebke et al., 2020).

The lack of sex-specific dietary differences suggests sex equality in nutrition or, at least, similar protein intakes. Data from comparable Swiss Neolithic burials support this result (Siebke et al., 2020; Lösch et al., 2020; Fig. 1). Higher mobility of females as evidenced by the higher variability in $\delta^{34}S$ values (Fig. 14) and the absence of kinship in the maternal line indicates a virilocal society (Furtwängler et al., 2020, Siebke et al., 2020).

Healed fractures and the severe osteomyelitis observed on a femur imply a caring, altruistic society. While the latter individual survived the infection for several months, sepsis proved probably fatal. Because of the fragmentary appearance of the remains, a detailed analysis of pathological alterations could not be performed (Siebke et al., 2019). However, Lösch et al. (2020) present graphic documentation of selected pathological alterations. A systemic Salmonella infection might have caused another death (Key et al., 2020).

The evidence of a former migration from the Near East (Furtwängler et al., 2020) is consistent with palaeogenetic studies of early Neolithic humans (Haak et al., 2010; Lazaridis et al., 2014, Sánchez-Quinto et al., 2019). The genetic influence from the Pontic steppes observed from 2800 BCE onwards (Allentoft et al., 2015; Haak et al., 2015) was still absent in the Oberbipp samples. According to the stable isotope data, despite a slightly higher female short-distance mobility, the individuals from Oberbipp had a sedentary lifestyle (Siebke et al., 2020).

4.8. Conclusions

The Oberbipp dolmen is a prime example of a site where extraordinary preservation and state-of-the-art documentation during the excavation allowed a multidisciplinary research approach, interlinking archaeological and anthropological evidence with environmental studies. In combination with the results of the anthropological study of the human remains (Siebke et al., 2019; Siebke et al., 2020; Furtwängler et al., 2020; Key et al., 2020), the generated data advances our understanding of the construction and use of megalithic funerary monuments in Central Europe. In the context of similar recent research with a regional focus, e.g. for northern Spain (Alt et al., 2016), western Ireland (Beckett, 2011) or southern Sweden (Blank et al., 2021), our comprehensive study contributes information to questions of social dynamics, mobility patterns, the evolution of Neolithic burial practices, and the spread of megalith structures on a broader European scale as presented for example by Schulz Paulsson (2019). It can also add further information to studies on kinship in Neolithic societies, as discussed by Sánchez-Quinto et al. (2019).

While the monument complements the Swiss ensemble of Late Neolithic burial structures, it also raises new questions. Oberbipp is the first example of this burial type discovered south of the Jura Mountains but away from the lakeshores, which were densely settled in prehistoric periods. The possible settlement remains found in proximity add weight to the question of Late Neolithic land use on the Swiss Central Plateau. In our opinion, a future focus of archaeological surveys on topographically “privileged” locations could allow the discovery of similar sites. Future studies aimed at multiphase use in combination with differentiated dating might allow a more comprehensive archaeological assessment of the dolmen landscape of Switzerland.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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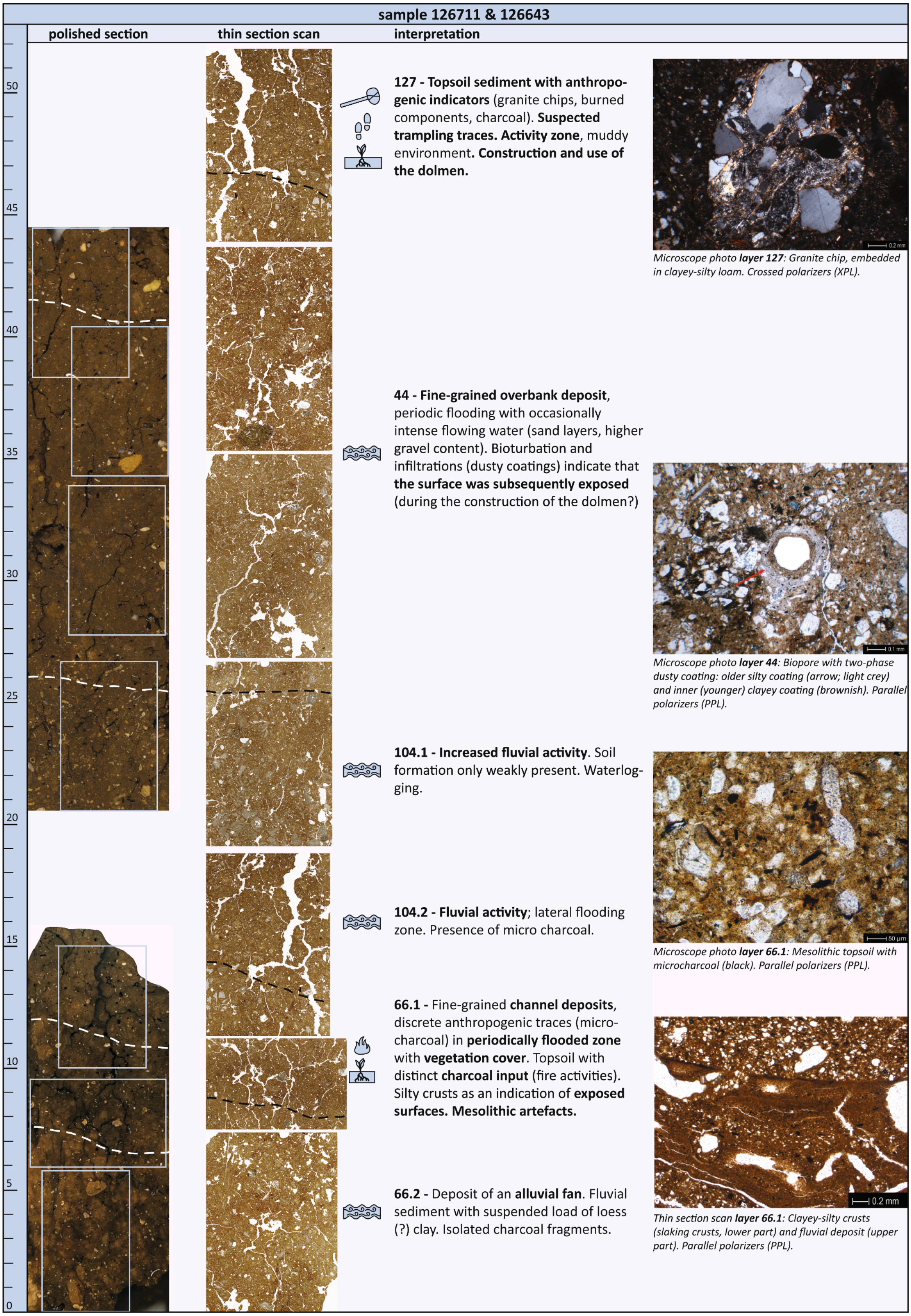
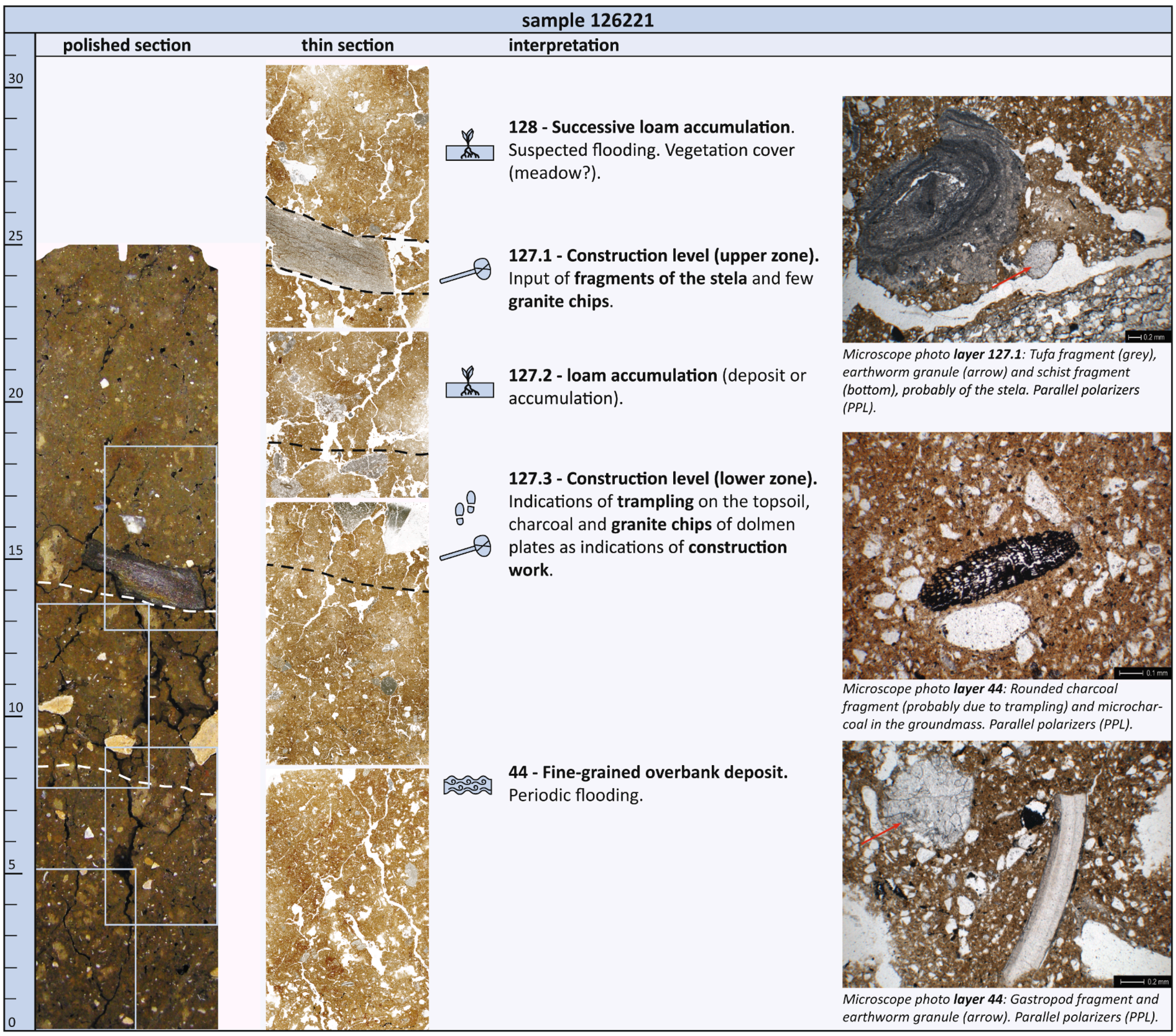
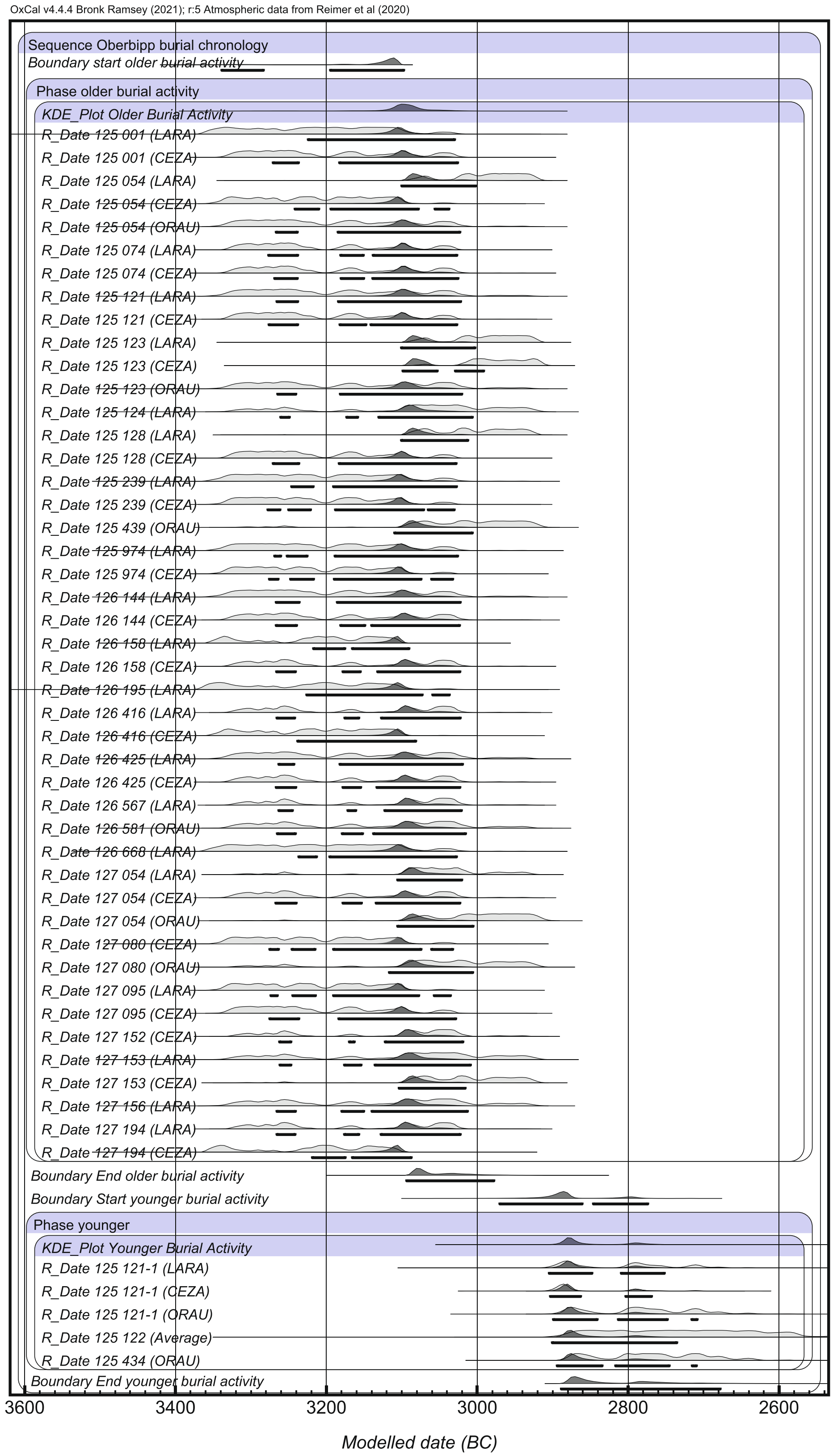
Annex



Annex 1. Results of the micromorphological analysis regarding (micro-) components and post-depositional processes of the soil samples 126711, 126643, and 126221.



Annex 1. (*continued*).



Annex 2. Bounded phase model (Amodel=77) of the dated femora (n=32, Steuri et al., 2019) using Phase, Boundary and KDE plot functions of OxCal v.4.4.4 (Bronk Ramsey, 2009) with default settings (Bronk Ramsey, 2017).

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