RESEARCH ARTICLE

Pleistocene freshwater ostracods from the *Homo erectus* site at Bilzingsleben, Germany—Review of historic collection and unpublished manuscript material for palaeoenvironmental reconstruction

Thomas Daniel 🔸 | **Peter Frenzel**

Institute of Geosciences, Friedrich-Schiller-University Jena, Jena, Germany

Correspondence
Thomas Daniel, Institute of Geosciences, Friedrich-Schiller-University Jena, 07749 Jena, Germany.
Email: thomas.daniel@hotmail.de

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Abstract

We provide a review of micropalaeontological research on Ostracoda from the Middle Pleistocene (MIS 11, Holstein interglacial) hominin site Bilzingsleben in Thuringia in Central Germany from 1963 to the 1990s. Samples from four sections inside and six search pits outside the excavation area were investigated and, in total, 49 ostracod species were identified. The ostracod assemblages of the sections mirror the complex and small-scale palaeoenvironmental evolution of the site from a seeping-spring to fluviatile, lacustrine and finally seeping-spring habitat in which a massive tufa layer formed and prevented erosion of the sediments beneath. Pleistocene index fossils are represented by *Ilyocypris quinculminata* from search pit 3/sample 9933 and *Scottia browniana* from section 70. Both species indicate the age dating of MIS 11 for the tufa deposit. The results of this study facilitate new insights into site formation processes, enable refinement of the interpretation of the archaeological record and shed light on the question: Does the find-bearing layer at the Bilzingsleben site contain in situ remains of a camp site of *Homo erectus* or not? Our results suggest that the site is not unaffected at least.

KEYWORDS
actualistic approach, Holstein interglacial, Ostracoda, palaeo air temperature, palaeosalinity, tufa

1 | INTRODUCTION

The *Homo erectus* site Bilzingsleben, a former tufa quarry, is located c. 2 km North-West (NW) of the town Kindelbrück (Figure 1a,c) in the northern part of the Federal State of Thuringia in Central Germany (Figure 1b). Here, the Kindelbrück fault zone, with Hercynian orientation from NW to South-East (SE), offsets Upper Muschelkalk (Anisium, Ladinium) against Lower Keuper (Norium, Rhaetium)

(Unger, 1963). The faults cause increased subsurface erosion of the Muschelkalk limestones, resulting in numerous dry but also active karstic springs in the vicinity of the site, such as the Gründelsloch at the western periphery of Kindelbrück (Figure 1a). The spring-water is enriched in calcium and precipitates tufa, which forms deposits of tufa sands, lacustrine lime and massive tufa banks, such as those at the Steinrinne, which is the local name of the archaeological site. The recent elevation of the site c. 27 m above the river valley results from
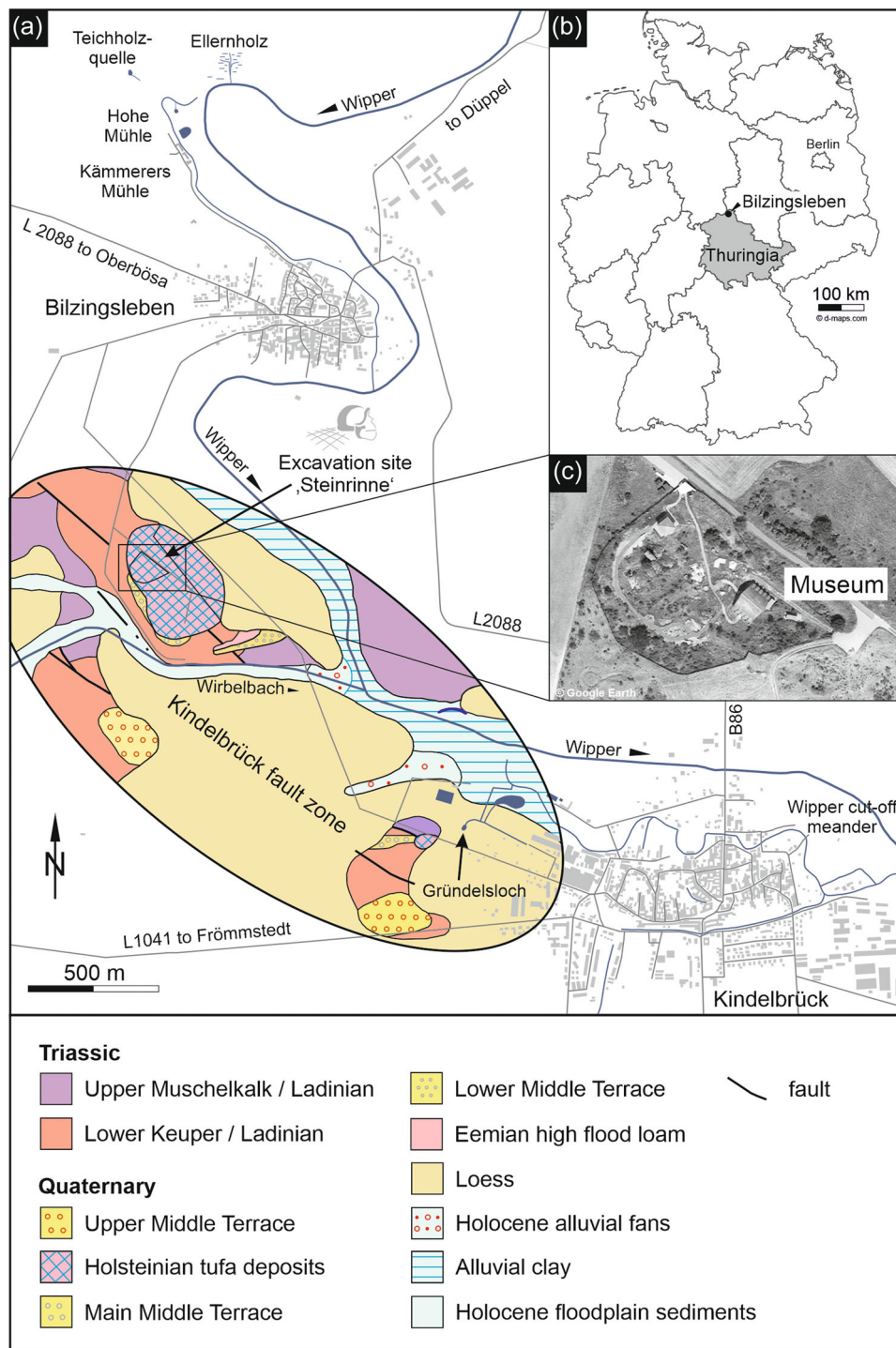
FIGURE 1 (a) Local map of Kindelbrück and Bilzingsleben with the Steinrinne site in the Southwest, based on the topographic map M-32-35-A-c-1 Frömmstedt (West) and M-32-35-A-c-2 Kindelbrück (East), 1:10,000, 1993, and the digital geological map 1:25,000 (map services of the TLUG/TLUBN). (b) Location of Bilzingsleben in Thuringia, Central Germany. (c) Aerial view of the site with the visitors' pavilion (upper left) and the museum hall.

relief inversion caused by the massive tufa bank that formed c. 370,000 years ago in the Holstein interglacial period (Mania & Altermannn, 2004). It prevented erosion of the unconsolidated tufa sand beds and lacustrine lime beneath and preserved the archaeological record enclosed in these sediments (Mania, 1990).

1.1 | Scientific controversy

For more than four decades, from 1963 to 2007, thousands of finds were excavated at the Bilzingsleben site: bones of bears, horses, woodland elephants, rhinos, bovids, suids and many more

(Mania & Mania, 2001). The most important and significant finds were the remains of *H. erectus* and his legacies in the form of flint and other stone and bone tools. Based on the *H. erecuts* bone finds, at least four individuals could be distinguished (Vlček, 2002).

The excavations carried out over decades continually brought new findings and refined the scientists' ideas about the site. Sedimentological and palaeontological investigations of the layer sequences enabled the identification of an alluvial fan and a shore area (Figure 2b). In the shore area numerous mammal bones, elephant tusks, large stones and charcoal remains were found and interpreted as an almost in situ record of a Lower Palaeolithic hunting camp with outlines of huts with fireplaces, distinct
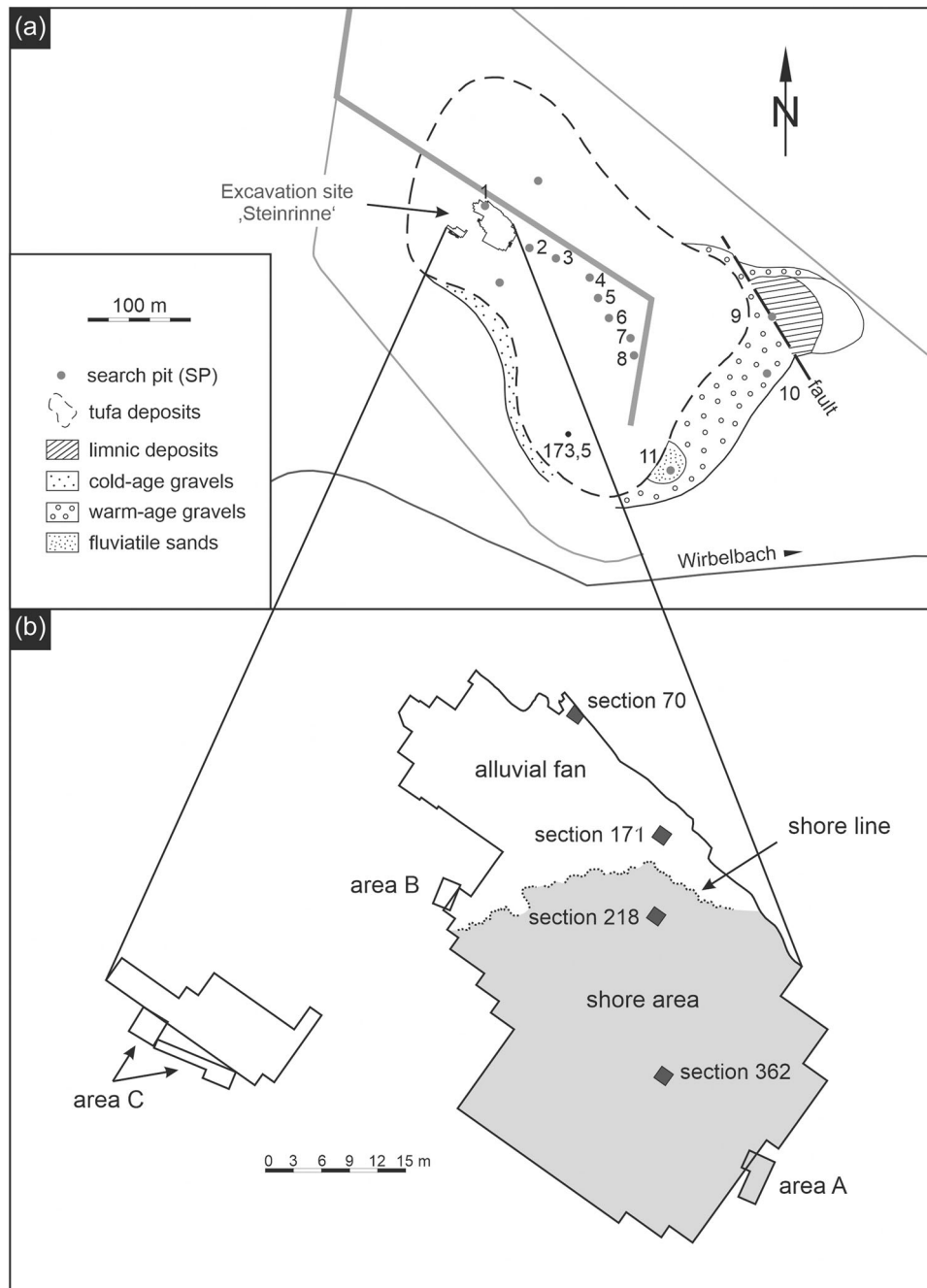

FIGURE 2 (a) Location of the excavation site and the search pits in the outcrop area of the Bilzingsleben tufa deposits. The search pits (SPs) are indexed with their numbers. SP 2–6 and 11 yielded ostracods. (b) Spatial interpretation of the excavation site with a shore area (grey) and an alluvial fan (white). The main excavations were carried out between 1969 and 2002. Areas A–C were excavated in 2003–2007, of area C the southern and south-western quadrants only (arrows). Compiled from Mania (1980), Mania et al. (2004) and Beck et al. (2007) and a current topographic map.

activity zones and an area which is supposed to have been deliberately paved with bones and stones (Mania, 1990). A large proportion of the archaeological finds, on the other hand, were found in the alluvial fan close to the shore area. The latter, moreover, was incised by small streams whose channels are filled with tufa sand. The rising water level of a forming lake later flooded the shore area and the archaeological record was covered by tufa sand and lacustrine lime (Mania, 1990). A massive tufa bank protected the sediments from erosion and thus the archaeological findings have been preserved until our time.

Since bones, stones, lithics and other finds of excavations conducted in 2003–2007 show a vertical scatter of c. 1 m and distinct orientation patterns in three sections (Figure 2b, sections A–C), the site interpretation as in situ findings have been challenged by Beck et al. (2007), Müller and Pasda (2011), Pasda (2012) and Liebermann and Pasda (2014). They doubt that the distribution of finds at the shore area represents an in situ record and instead make natural environmental and sedimentation processes accountable for the vertical and lateral scatter of stones, bones and lithics. A gravitational mass flow theory was developed, according to which these should have led to the chaotic distribution of finds (Beck et al., 2007). Brasser (2017) stated, after investigating bones excavated in 1971–2002, that the hominids were certainly part of the natural environment but no signs of zonal activities in this area could be deduced from the distribution of mammal bones. The inventory of the site was subjected to fluviatile relocation and to a series of other taphonomic processes during and after being frequented by animals and hominids (Brasser, 2017). The question now is: Does the Bilzingsleben site contain in situ remains of a prehistoric hunting camp or do the archaeological finds have to be considered as relocated according to the gravitational mass flow theory?

1.2 | Micropalaeontological approach

Since ostracods are reliable indicators for various environmental parameters in aquatic sediments, for example, salinity, temperature, habitat structure, water chemistry and transport conditions, they have a great potential for ecological monitoring and palaeoenvironmental analyses (Frenzel & Boomer, 2005; Griffiths & Holmes, 2000). In Quaternary sediments, the value of ostracods as bioindicators is augmented because most species are extant and can be studied alive in their natural environment. For this reason, they are excellent implements for an actualistic approach for the reconstruction of palaeoenvironments and are increasingly used for the clarification of such questions (Quante et al., 2022).

Although numerous papers and books about the Bilzingsleben excavation site have been published—Mania and Mania (2001) summarize 30 years of Bilzingsleben research and Brühl (2015) provides a summary of the most important articles and books—only a few dealt with freshwater ostracods: Unger (1963), Diebel (1979) and

Diebel and Pietrzeniuk (1980). Since then, Erika Pietrzeniuk (1935–2015) had conducted more research on ostracod assemblages and the tufa sequence at the Bilzingsleben site. For various reasons, however, these results were never published.

This study aims to contribute to the refinement of the interpretation of the archaeological record by examining the diverse freshwater ostracod fauna studied and documented by Erika Pietrzeniuk to reconstruct the environmental conditions of the site affecting aquatic species and their distribution in space and time. With this palaeoenvironmental data set, the interpretation of site formation processes can be substantiated and improved.

2 | MATERIALS AND METHODS

The micropalaeontological material investigated in this study is housed in the micropalaeontology collections of the Museum of Natural History in Berlin (MfN). More than 650 microslides with picked and identified ostracod valves from sections 70, 171, 218 and 362 (Figures 3–6), five search pits 2–6 (dredge excavations, hereafter referred to as pit or abbreviated SP) from Holsteinian deposits and one from Eemian sediments (pit 11, sample 2478) of the Bilzingsleben site (Figure 2) were reviewed, checked at the museum and also loaned for further investigation and photographic documentation. The valves were counted semiquantitatively and listed in six abundance classes: 1–2, 3–5, 6–10, 11–25, 26–100 and >100 specimens, as already done by Pietrzeniuk. The documentation of ostracod analyses (unpublished data), for example, drawings of sections, photographs of ostracods and compiled tables, was reviewed, digitized and edited in this study on behalf of E. Pietrzeniuk. The taxonomical identification of ostracods was checked based on Diebel and Pietrzeniuk (1975, 1977, 1978, 1980, 1984), Meisch (2000) and Fuhrmann (2012). Stratigraphic, ecological and habitat interpretation relies on Griffiths (1995), Meisch (2000) and Fuhrmann (2012). The taxonomy is based mainly on Meisch (2000). An exception is made for *Cyclocypris taubachensis*, which refers to the taxonomic opinion of Fuhrmann (2012). Determination of charophyte gyrogonites was done by Ingeborg Soulié-Märsche, University of Montpellier. For palaeo air temperature reconstruction, the Mutual Ostracod Temperature Range (MOTR) by Horne (2007), Horne and Mezquita (2008) and Horne et al. (2012), as well as calibrated data by Dave Horne (personal communication, January 5, 2012), were applied to the ostracod assemblages. Salinity estimation was conducted with data from Frenzel et al. (2010) and Pint et al. (2015, 2017); it is given in PSUs (practical salinity units), which corresponds to per mille (‰).

Since the information value of the ostracod assemblages of the samples from the five Holsteinian pits is limited, this study focuses on the sections from the excavation area (Figure 2b) regarding palaeoenvironmental reconstruction. The ostracod assemblage of sample 2478 from pit 11, which is situated c. 270 m southeast of the
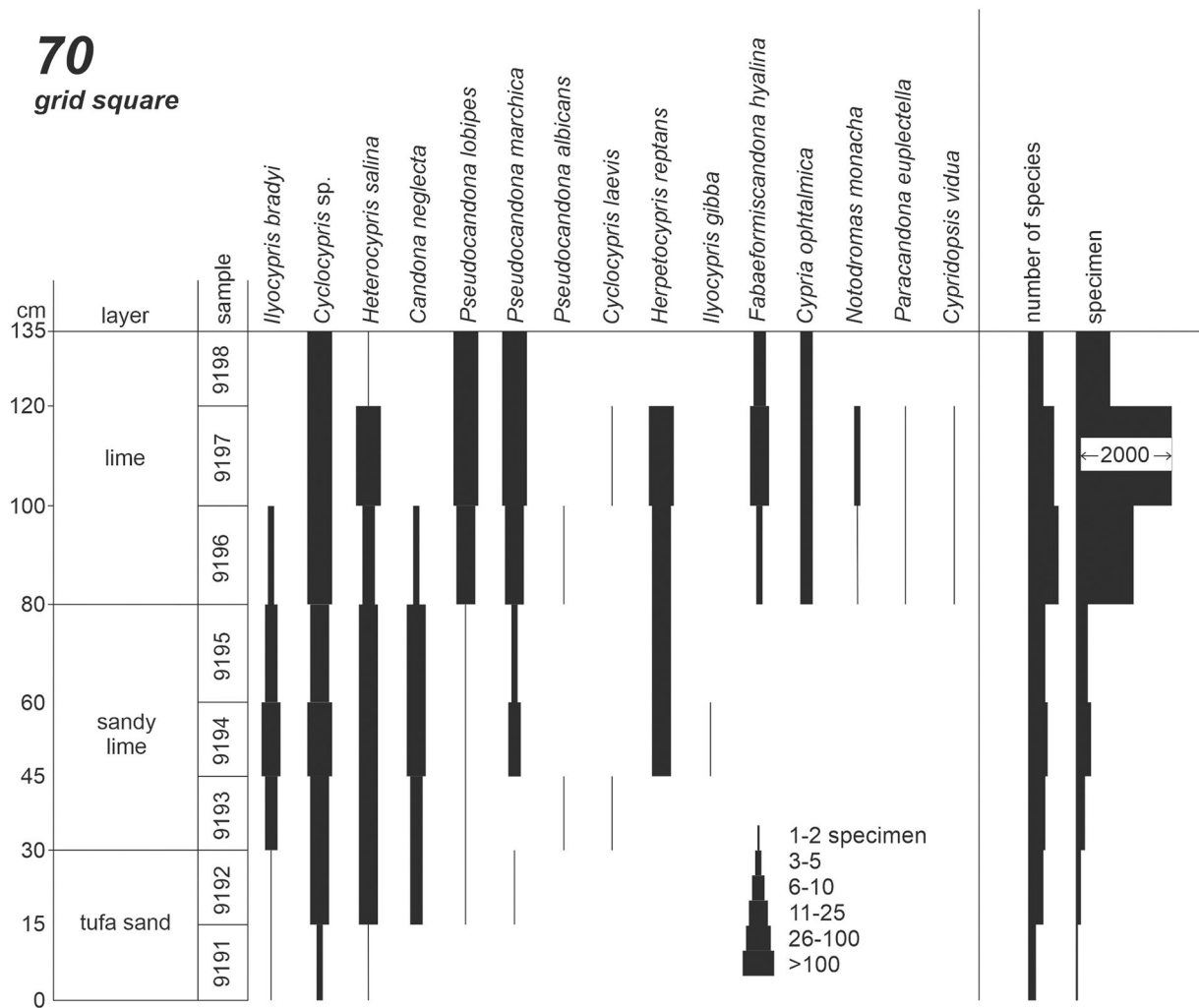
FIGURE 3 Distribution of ostracod taxa in section 70, modified from by Diebel and Pietrzeniuk (1980).

excavation area, was included for palaeo air temperature estimation of the Eem interglacial.

3 │ RESULTS

3.1 │ Preservation of microfossils

The preservation of ostracod valves is exceptionally good due to conservation in a tufa setting and the covering of soft and loose sediment layers by a compact tufa bank. In parts, some signs of superficial dissolution occur. Internal moulds were predominantly found in the sandy layers rich in siliciclastics and in covering layers consisting of tufa sands. Most of the moulds within the siliciclastics-rich layers belong to Mesozoic ostracods eroded from the surrounding areas. They consist of siliceous material as well. The moulds from tufa sands are composed of calcite and represent filled and then broken and/or dissolved Quaternary ostracod valves. In the lime abundant remnants of charophytes were found together with the

documented ostracods. Charophytes have been preserved as hollow calcified oospores and stem remnants of *Chara hispida* and minor *Chara vulgaris*.

3.2 │ List of ostracod taxa

In total, 49 freshwater ostracod species were identified from the Bilzings-le-ben site and are listed alphabetically in Table 1. The most abundant taxa are *C. taubachensis*, *Heterocypris salina*, *Pseudocandona lobipes*, *P. marchica*, *Ilyocypris bradyi* and *Herpetocypris reptans* (Figures 3–8).

3.3 │ Sections

The location of the four sections investigated refers to the excavation map by Mania et al. (2004) and is indicated with the numbers of the excavation grid squares 70, 171, 218 and 362 (Figure 2b).
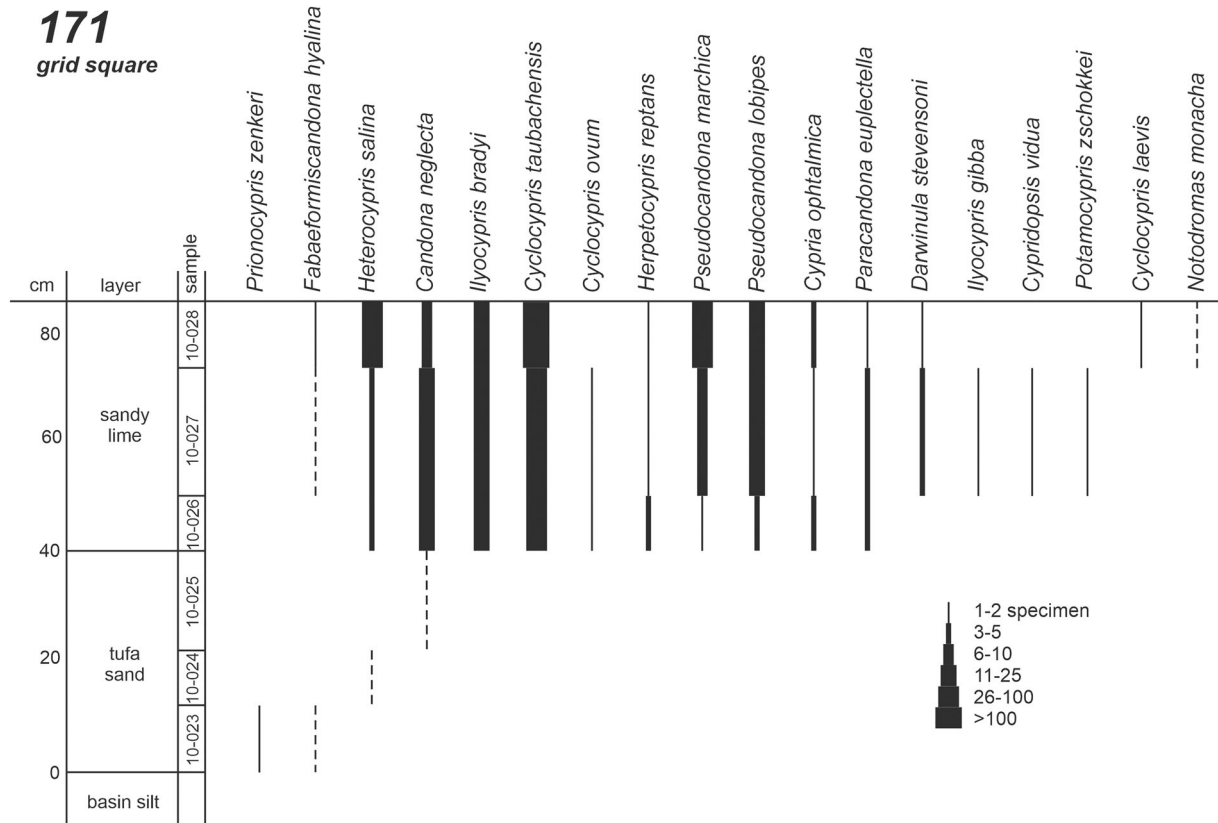
FIGURE 4 Distribution of ostracod taxa in section 171. Ostracod finds from bulk samples are indicated with dashed lines.

3.3.1 | Section 70

This section (Figure 3) was investigated in the first study on ostracods from the Bilzingsleben site. It consists of tufa sand, sandy lime and pure lime. Diebel and Pietrzeniuk (1980) discovered an ostracod association of more than 30 species, with 12 species dominating and being important for palaeoenvironmental reconstruction.

The tufa sand yields *Candona neglecta*, *H. salina* and *C. taubachensis*. *I. bradyi* is scarce and in the upper part of the tufa sand *Pseudocandona marchica* and *P. lobipes* occur with few specimens. The rare occurrence of *Scottia browniana* appearing in samples 9192 and 9195 (Table 2) is important for the dating of the site since it is an index fossil for the Lower and Middle Pleistocene (Fuhrmann, 2012). *I. bradyi* and *Heterocypris reptans* become more abundant in the sandy lime, and species diversity increases, although most species occur with low valve counts only (Table 2). The total number of valves peaks at 2000 in sample 9197, which also showed the highest species diversity.

At 80–90 cm above the base of a compact tufa bank, Diebel and Pietrzeniuk (1980) sampled a tufa sand lens that provided a rich fauna of ostracods, gastropods and fragments of *Taubachia* sp. (head capsules of larvae of Stratiomyidae, soldier flies). In the accompanying ostracod assemblage abundant *Microdarwinula zimmeri* occurs.

3.3.2 | Section 171

Section 171 (Figure 4) is composed of tufa sand and sandy lime, has a total thickness of c. 80 cm and is cut at the top of the lime due to quarry operation. The ostracod fauna of the tufa sand has a very low diversity and abundance with only *Prionocypris zenkeri* present with one specimen in 100 g sediment. *Fabaeformiscandona hyalina*, *H. salina* and *C. neglecta* could only be obtained from large-volume samples. With the beginning of the sedimentation of lime interspersed with tufa sand, more ostracod species occur, and diversity increases significantly. The ostracod assemblage of the sandy lime becomes relatively stable. *Cyclocypris laevis* and *Notodromas monacha* are restricted to the uppermost sample. A few reworked Mesozoic ostracods (not pictured here) were found in the tufa sand and the sandy lime.

3.3.3 | Section 218

Section 218 (Figure 5) comprises a total sediment thickness of c. 160 cm and is composed of sandy lime, pure lime, loose tufa and a massive tufa bank with intercalated tufa sand lenses.

The basal sandy lime yields a species assemblage consisting of *C. neglecta*, *I. bradyi*, *H. salina* and *C. taubachensis*. *H. salina* and *C. taubachensis* are dominant. Mesozoic ostracods occur only in the basal
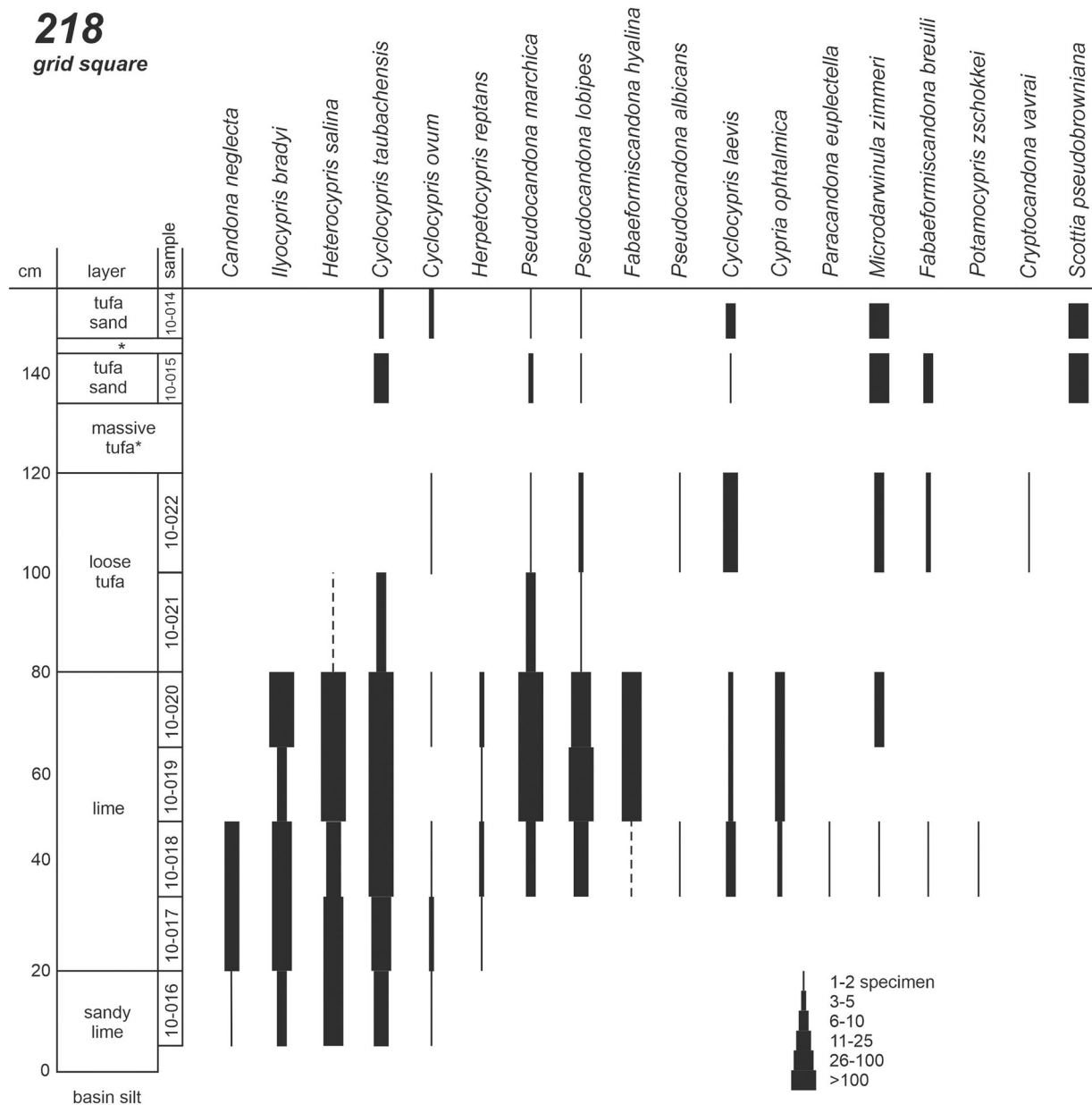
FIGURE 5 Distribution of ostracod taxa in section 218.

sandy lime. With the shift to lime, more species contribute to the association which is most diverse in the lower half of the lime layer (sample 10-018). Here, among others, such rare species occur as *Pseudocandona albicans*, *Paracandona euplectella* and *Potamocypris zschokkei*. The dominant species, except for *C. neglecta*, also occur in the uppermost part of the lime in samples 10-019 and 10-020, whereas *P. albicans*, *P. euplectella* and *P. zschokkei* disappear.

With the shift from lime to loose tufa in sample 10-021, the faunal assemblage impoverishes and species such as *I. bradyi* and *F. hyalina* disappear. Other species, such as *P. albicans*, *M. zimmeri* and *F. breuili*, occur again.

Two additional samples (10-014 and 10-015) were taken from tufa sand lenses within the massive tufa bank at the top of the

section. Both yielded *Scottia pseudobrowniana* and *M. zimmeri* with relatively high abundance, as well as a few other ostracod species.

3.3.4 | Section 362

Section 362 (Figure 6) has a total thickness of c. 110 cm and consists of a compact tufa bank with intercalated tufa sand layers. This bank is overlain by loose tufa, lime and yet another layer of loose tufa. An alternating sequence of compact and loose tufa builds the top of the section. The sandy layers within the compact tufa bank contain very diverse ostracod assemblages dominated by *S. pseudobrowniana*, *M. zimmeri*, *C. taubachensis*, *F. breuili*, *P. lobipes*, *C. laevis* and *Cypria*
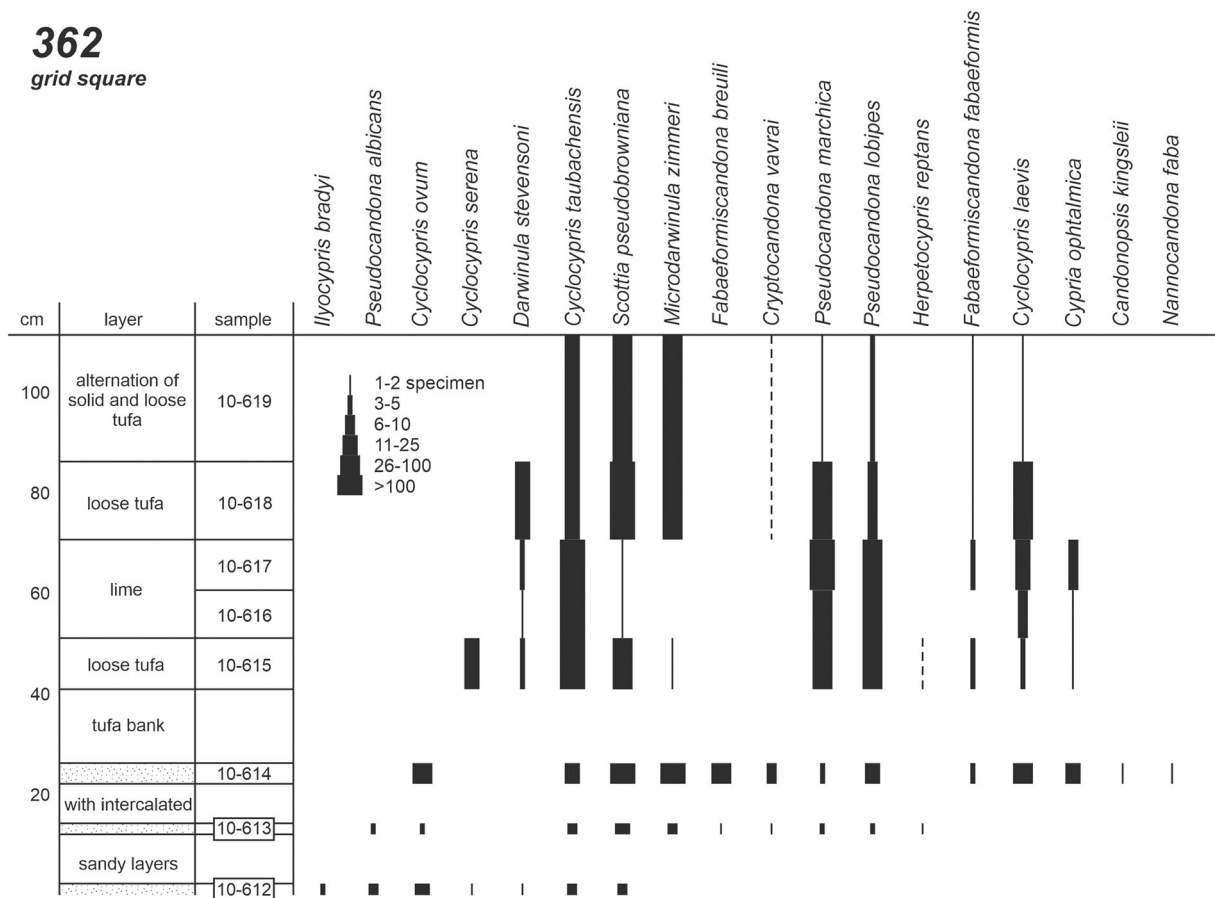
FIGURE 6   Distribution of ostracod taxa in section 362.

ophtalmica. The lowermost sample 10-612 also contains a few valves of *Cyprideis torosa*. The ostracod fauna from the loose tufa is less diverse and is characterized by the mass occurrence of *C. taubachensis*, *S. pseudobrowniana*, *P. marchica* and *P. lobipes*. The samples from the lime contain a faunal assemblage, which is less diverse but rich in individuals with the dominating species *C. taubachensis*, *P. marchica* and *P. lobipes*. The relative abundance of *S. pseudobrowniana* declines together with *Darwinula stevensoni* but increases for *C. laevis* and *C. ophtalmica*. With the transition from lime to loose tufa in sample 10-618, species abundance rises, but *C. ophtalmica* disappears. In the alternating sequence of compact and loose tufa on top, *S. pseudobrowniana*, *M. zimmeri* and *C. taubachensis* are still dominant, whereas *Cryptocandona vavrai*, *P. marchica*, *P. lobipes*, *F. fabaeformis* and *C. laevis* are present with few or single valves only.

3.4 | Pit 11 (Eem Interglacial)

During field mapping, Unger (1963) discovered fluviatile sediments close to the Steinrinne quarry and sampled a section of 'gastropod-sands' and 'gastropod-marls'. The calcareous sediment of sample 2478 contained gastropods, charophytes and fish remains. It also

comprised a very diverse and abundant ostracod fauna with a total number of 9720 valves. The most abundant species (72%) is *Limnocythere inopinata* with an amphigonic population with a 7:3 relation of females to males. Other species are represented by *P. marchica* (1%), *Pseudocandona* sp. (juveniles 7%), *H. salina* (5%), *Candona candida* (3%) and *Candona* sp. (2%). Minor species are *Ilyocypris* sp. (3%), *I. bradyi* (1%), *Cyclocypris ovum* (2%), *Cyclocypris* sp. (2%) and *Nannocandona faba* (1%). *C. laevis*, *C. serena*, *H. reptans*, *P. zenkeri*, *F.* cf. *balatonica*, *Cavernocypris subterranea*, *Ilyocypris inermis*, *Potamocypris fallax* and *Eucypris pigra* occur with less than 1% in the faunal assemblage.

3.5 | Palaeo air temperature

By applying the MOTR method by Horne (2007), Horne and Mezquita (2008) and Horne et al. (2012) to the ostracod assemblages of the excavation area, the mean July air temperature lay somewhere between +16°C and +20°C, while the mean January air temperature was somewhere between −4°C and +4°C (Figure 9). The most indicative species are *F. hyalina*, *P. zenkeri* and *S. pseudobrowniana*, which are described by Meisch (2000) as oligothermophilic. With regard to the MOTR method, it should be noted that the MOTR

TABLE 1 Alphabetical list of ostracod taxa from the Bilzingsleben site, Thuringia, Germany compiled from Diebel (1979), Diebel and Pietrzeniuk (1980), unpublished data from Erika Pietrzeniuk and new investigations (Daniel et al., in preparation).

Candona angulata (Müller, 1900)
Candona candida (O. F. Müller, 1776)
Candona neglecta (Sars, 1887)
Candona weltneri (Hartwig, 1899)
Candonopsis kingsleii (Brady & Robertson, 1970)
Cavernocypris subterranea (Wolf, 1920)
Cryptocandona vavrai (Kaufmann, 1900)
Cyclocypris diebeli (Absolon, 1973)
Cyclocypris laevis (O. F. Müller, 1776)
Cyclocypris ovum (Jurine, 1820)
Cyclocypris serena (Koch, 1838)
Cyclocypris taubachensis (Diebel & Pietrzeniuk, 1984)
Cypria ophtalmica (Jurine, 1820)
Cyprideis torosa (Jones, 1850)
Cypridopsis hartwigi (G. W. Müller, 1900)
Cypridopsis lusatica (Schäfer, 1943)
Cypridopsis vidua (O. F. Müller, 1776)
Cyprois marginata (Straus, 1821)
Cypris pubera (O. F. Müller, 1776)
Darwinula stevensoni (Brady & Robertson, 1870)
Eucypris pigra (Fischer, 1851)
Fabaeformiscandona angusta (Ostermeyer, 1937)
Fabeformiscandona cf. *balatonica* (Daday, 1894)
Fabaeformiscandona breuili (Paris, 1920)
Fabaeformiscandona fabaeformis (Fischer, 1851)
Fabaeformiscandona hyalina (Brady & Robertson, 1870)
Herpetocypris brevicaudata (Kaufmann, 1900)
Herpetocypris reptans (Baird, 1835)
Heterocypris incongruens (Ramdohr, 1808)
Heterocypris salina (Brady, 1868)
Ilyocypris bradyi (Sars, 1890)
Ilyocypris gibba (Ramdohr, 1808)
Ilyocypris inermis (Kaufmann, 1900)
Ilyocypris quinculminata (Sylvester-Bradley, 1973)
Limnocythere inopinata (Baird, 1843)
Microdarwinula zimmeri (Menzel, 1916)
Nannocandona faba (Ekman, 1914)
Notodromas monacha (O. F. Müller, 1776)

TABLE 1 (Continued)

Paracandona euplectella (Robertson, 1889)
Potamocypris sp. A
Potamocypris fallax (Fox, 1967)
Potamocypris villosa (Jurine, 1820)
Potamocypris zschokkei (Kaufmann, 1900)
Prionocypris zenkeri (Chyzer & Toth, 1858)
Pseudocandona albicans (Brady, 1864)
Pseudocandona lobipes (Hartwig, 1900)
Pseudocandona marchica (Hartwig, 1899)
(Brady & Norman, 1889)
Scottia browniana (Jones, 1850)
Scottia pseudobrowniana (Kempf, 1971)

Note: Not all species occur in the species distribution diagrams of this study, but were reported in the literature, found in search pits outside the excavation area or documented by new investigations on ostracods (Daniel et al., in preparation). Meisch et al. (2019) list *Candona angulata* and *Candona neglecta* under the genus *Neglecandona*. We use the older genus *Candona* here. *Potamocypris* sp. A is a new species from search pit 3/sample 9933 discovered by E. Pietrzeniuk and shall be described later.

method uses, as a standard for species' calibrations, the WorldClim interpolated climate data representing averages for the period 1950 to 2000 (www.worldclim.org). For Bilzingsleben the WorldClim database provides the following 'present-day' temperature values: January: −0.1°C and July: +17.6°C. Since the climate has already changed slightly in the past two decades due to anthropogenic CO_2 emissions, the values of the WorldClim database deviate somewhat from the recently measured mean temperature values. Present-day average temperatures of +0.8°C in January and +19.9°C in July were recorded at the Kindelbrück meteorological station close to the Bilzingsleben site in the years 2007 to 2021. Nonetheless, both the WorldClim and the current temperature averages determined at the Kindelbrück station plot in the MOTR field, thus indicating very similar temperatures for January and July today as compared to the Holsteinian palaeoenvironment of Bilzingsleben.

Temperature estimations (Mania, 1990; Figure 9) based on fossil floral elements from the Bilzingsleben tufa point to a Central European to sub-Mediterranean climate with a temperature range of −0.5°C to +3°C in January and +20°C to +25°C in July with a mean of +20.5°C. Both the winter and summer temperature ranges overlap the equivalent MOTR ranges, even though only the minimum of the July floral range matches the maximum of the July MOTR range.

For palaeo air temperature reconstruction of the Eemian deposit (search pit 11; Figure 10), only two species were indicative: *C. subterranea* and *P. zenkeri*. The species reflect a temperature range
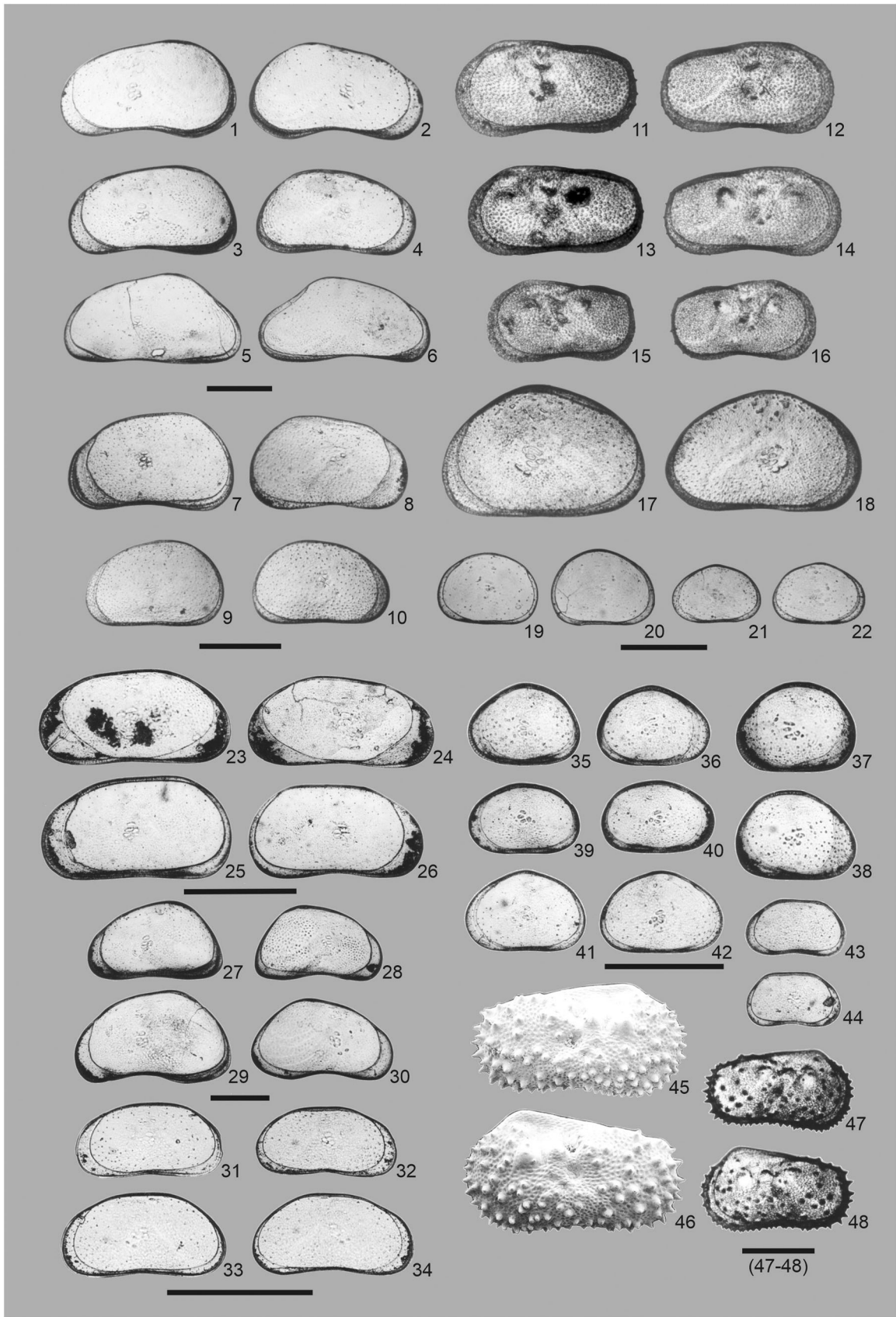
FIGURE 7 (See caption on next page)

of −4°C to +4°C in January and +14°C to +20°C in July. Compared to the temperature range of the Holsteinian, the average temperature in July deduced from ostracods from the Eemian interglacial deposit shows a minimum two degrees lower and may indicate slightly colder summers compared to the Holsteinian palaeoclimate. This temperature estimation, however, is subject to greater uncertainties since the indicative ostracod species do not occur with abundant valve counts.

3.6 | Salinity

The salinity range estimation of the former water body (Figure 11) was conducted with ecological data given by Frenzel et al. (2010) for the southern Baltic Sea area and by Pint et al. (2015, 2017) for Central Germany. Species limiting the salinity range from 0.4 (freshwater) to 3.6 PSU (oligohaline) are *C. torosa* for the lower limit and *P. lobipes* for the upper one. *C. torosa* is well known from brackish waters and lives in shallow coastal waters as well as in saline inland waters (Fuhrmann, 2012). It can tolerate slightly brackish to hypersaline conditions (Meisch, 2000). Neale (1988) documents a maximum salinity tolerance of 150 PSU and Frenzel et al. (2010) stated a lower limit of 0.4 and that it is often dominant from 0.5 to 2 PSU (Figure 11). *C. torosa* is used as an indicator for brackish waters and as an index species in palaeosalinity reconstructions relying on water chemistry-bound morphological changes such as nodes and sieve-pore shapes (Pint et al., 2012). Since the species predominantly form nodes within a salinity range of 0.4–2 PSU (Frenzel et al., 2010), the occurrence of the species with smooth, unnoded valves in sample 9191 of section 70, although with very few valve counts, points to an increased salinity and may refer to a population of the species in more saline waters at a site close by. Due to the dissolution of salt by the subrosion processes, such sites are quite common in Central Germany (Pint et al., 2012). *P. lobipes* occurs in freshwater and β-oligohaline waters. It tolerates salinities up to 3.6 PSU (Frenzel et al., 2010; Meisch, 2000) and indicates the maximum salinity of the site.

3.7 | Palaeoenvironmental reconstruction

The palaeoenvironmental reconstruction of sections 70, 171, 218 and 362 of the Bilzingsleben site (Figure 12) was carried out based on their sedimentological, faunal and palaeoenvironmental data. This was not always clear, especially in case of sections 218 and 362, as different habitats were revealed by the data in a number of samples. Some ostracod species with specific requirements to their environment were very indicative (Table 3). In contrast, less importance in the reconstruction was given to other species with less restrictive environmental requirements. Unfortunately, sedimentological data such as grain-size analyses were not available for these sections, so we had to rely on the schematic section drawings and the ostacod data alone.

3.7.1 | Section 70

The ostracod assemblage of section 70 (Figure 3 and Table 2 with additional taxa) points to an initially shallow lacustrine (III-A), respectively, a fluviatile (II) and then fully lacustrine (III) habitat. *C. vavrai* and *P. fallax* indicate springs and spring-related waters (Meisch, 2000). *H. salina* can be an indicator for slightly saline conditions, but Meisch (2000), Fuhrmann (2012) and Pint et al. (2012) document the species in pure freshwater also. *C. torosa* from sample 9191 is exotic within the faunal association (Table 2). It can tolerate freshwater conditions but occurs in brackish water bodies in coastal environments in general. The tufa sand is interpreted as a spring-related sediment deposition into a shallow, lacustrine water body that was influenced by flowing water (II).

The ostracod fauna of the sandy lime (samples 9193-9195, habitat III-A) is more diverse than within the tufa sand. *D. stevensoni*, *C. ophtalmica*, *Cypridopsis vidua* and *E. pigra* point to a beginning stagnation phase of the water body which induced the sedimentation of pure lacustrine lime. *D. stevensoni* and *C. ophtalmica*, for instance, prefer stagnant water bodies but can also occur in flowing water (Fuhrmann, 2012; Meisch, 2000). The occurrences of *C. vavrai* and *P. fallax* indicate the influx of water coming from a spring, as both species live in springs (Fuhrmann, 2012). Internal moulds of Mesozoic (Anisian, Ladinian) ostracods occur in sample 9195 for the last time and indicate the decrease and then end of sediment input from external sediment sources.

The fauna of the pure lime is diverse and abundant and mirrors a standing water body (III). The dominant taxa, such as *Cyclocypris* sp., *P. lobipes*, *P. marchica* and *F. hyalina*, are found in swampy and muddy habitats with decaying organic matter (Meisch, 2000). Stagnant conditions without water movement are indicated by *C. ophtalmica*, *P. euplectella* and *N. monacha*. *C. ophtalmica* colonizes, besides a wide range of other aquatic habitats, ponds with fallen leaves and organic

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FIGURE 7 Ostracod taxa from the Bilzingsleben site. Photographs 1–22 by Diebel and Pietrzeniuk (1980), modified, 23–48 by Pietrzeniuk (unpublished, modified), 1–44 and 47–48 transmitted light, 45–46 scanning electon microscope images. **1–4** *Candona neglecta*, **1–2** male, **3–4** female. **5–6** *Fabaeformiscandona hyalina*. **7–8** *Pseudocandona marchica*. **9–10** *Pseudocandona lobipes*. **11–14** *Ilyocypris bradyi*. **15–16** *Ilyocypris gibba*. **17–18** *Heterocypris salina*. **19–20** *Cypria ophtalmica*. **21–22** *Cyclocypris* cf. *ovum*. **23–24** *Cryptocandona vavrai*, SP 3, sample 9933. **25–26** *Pseudocandona albicans*, sample 9933. **27–30** *Candona candida*, **27–28** female, **29–30** male, sample 9933. **31–34** *Fabaeformiscandona breuili*, SP 2, sample 9932. **35–36** *Cyclocypris laevis*, SP 3, sample 9933. **37–38** *Cyclocypris diebeli*, SP 3, sample 9933. **39–40** *Cyclocypris ovum*, SP 3, sample 9933. **41–42** *Cyclocypris taubachensis*, SP 3, sample 9933. **43–44** *Nannocandona faba*, SP 3, sample 9933. **45–48** *Ilyocypris quinculminata*, SP 3, sample 9933. Scale bars, 500 μm.
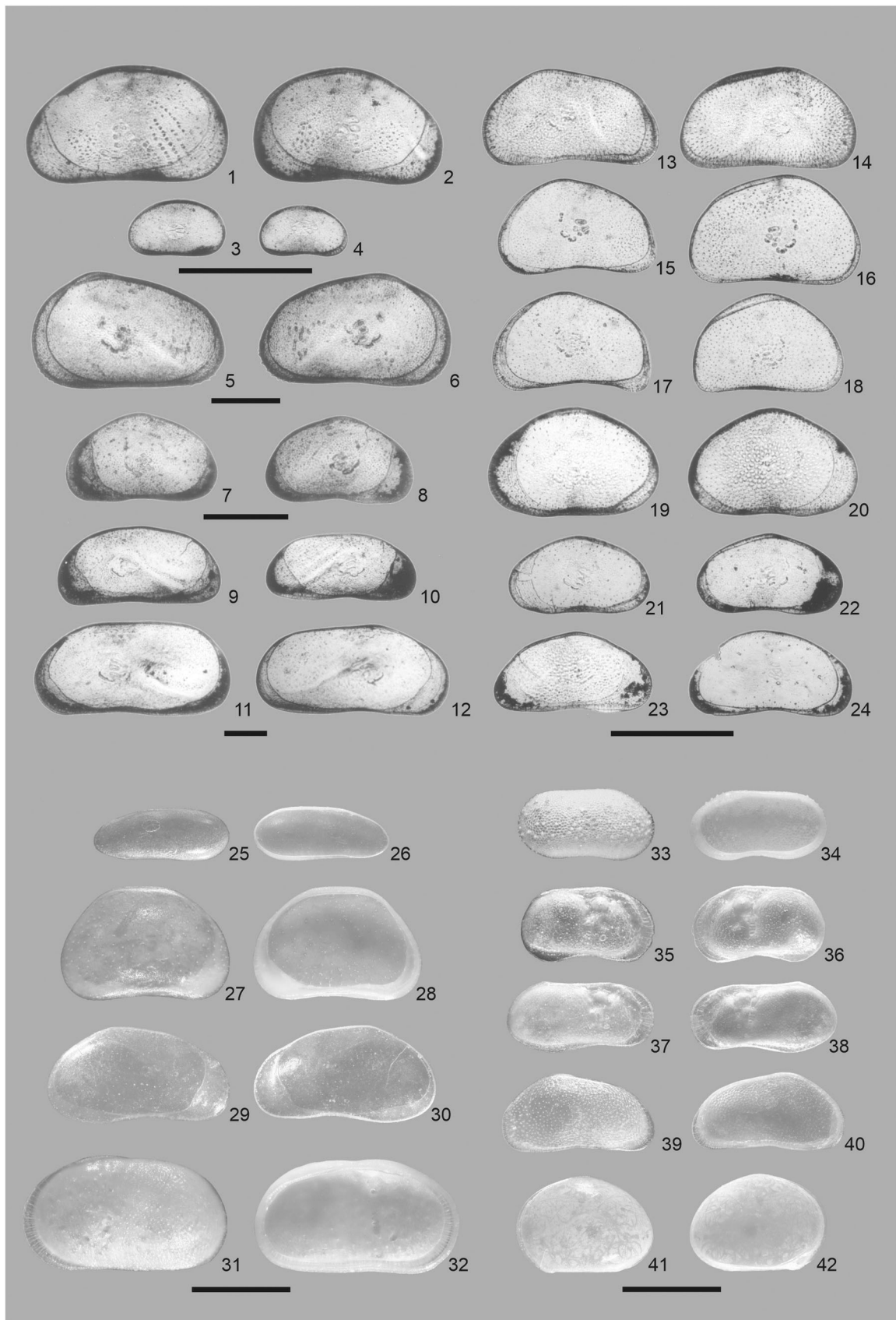
FIGURE 8 (See caption on next page)

detritus, and *P. euplectella* lives in small muddy and swampy water bodies (Meisch, 2000). *N. monacha* feeds on the residue film of the water surface and only occurs in still water areas (Meisch, 2000). The ostracod fauna of the tufa sand lens intercalated in the uppermost massive tufa bank shows abundant *M. zimmeri*, which points to seeping-spring habitats (IV) in which the dense and more cemented tufa bank formed. This tufa bank protected the underlying sediments from erosion and probably existed in all profiles. It was partially removed by centuries of quarrying.

3.7.2 | Section 171

The faunal association of section 171 (Figure 4) mirrors flowing water conditions for the tufa sand of samples 10-023 to 10-025. The rheophilic species *P. zenkeri* (Meisch, 2000) and the low abundance of ostracods are significant indicators of the fluviatile stage II. The sandy lime is diverse and rich in individuals with diversity peaking in sample 10-027. The lacustrine habitat III with sandy and a fine sandy to silty lake bottom can be deduced due to the presence of *P. marchica*, *P. lobipes*, *Cyclocypris* sp., *C. ophtalmica* and *P. euplectella*.

P. marchica* and *P. lobipes* both live in small, permanent water bodies (Meisch, 2000). The increased abundance of *H. salina* in sample 10-028 is possibly a result of a change in the chemistry of the water body caused by higher evaporation rates, decreasing water inflow and stagnant water conditions, the latter indicated by *N. monacha* (Meisch, 2000).

Section 171 is characterized by two different habitats gradually merging: a fluviatile habitat (II) with few species turning into a shallow stagnant water body with an abundant and diverse ostracod fauna (III).

3.7.3 | Section 218

The ostracod assemblage obtained from the tufa sand of sample 10-016 (Figure 5) indicates a sandy bottom in a shallow lacustrine habitat (III-A). The occurrence of *H. salina* may indicate increased salinity, possibly caused by evaporation and reduced water exchange. The faunal association changes insignificantly in sample 10-017 but the abundance of ostracods grows rapidly in a now fully established lacustrine habitat with a permanent water coverage (habitat III) indicated by *P. marchica*, *P. lobipes* and *C. ophtalmica*. *M. zimmeri* and

F. breuili* in sample 10-018 may originate from springs fed by groundwater and flowing into the lake as *M. zimmeri* occurs in seeping springs and *F. breuili* in the interstitial groundwater (Meisch, 2000). The inflow of the spring water is not verifiable for samples 10-019 and 10-021 but is detectable again above the lacustrine lime in the loose tufa. The habitat can be described as a shift from lacustrine (III) to a setting with seeping springs (IV) with humid to wet moss where tufa precipitated at the plant remains. *M. zimmeri*, *S. pseudobrowniana* and *F. breuili* are indicators of this habitat which was fed by freshwater-seeping springs.

3.7.4 | Section 362

A unique characteristic of section 362 (Figure 6) is the faunal assemblage with *S. pseudobrowniana* and *M. zimmeri* dominating in loose tufa at the base of the section and in the sandy limonitic layers intercalated in a massive tufa bank. In conjunction with *F. breuili*, *C. vavrai* and *Fabaeformiscandona fabaeformis* occurring in springs (Meisch, 2000), the species point to humid to wet moss cover and low vegetation percolated by freshwater in a semiterrestrial seeping-spring habitat (I-A/IV). The loose tufa of sample 10-615 prefigures an initial shallow lacustrine habitat III-A/IV with *C. taubachensis*, *C. serena*, *P. marchica* and *P. lobipes* as these species occur in stagnant water bodies (Meisch, 2000). This spring-related, semiterrestrial sediment became transgressed by a lake and stagnant water conditions developed with a possible detrital input of ostracod valves from habitats nearby. With the ongoing transgression, further areas of the former seeping-spring habitat (IV) were flooded and a fully lacustrine setting (III) developed, represented by the lime (samples 10-616 and 10-617). *M. zimmeri* is absent and *S. pseudobrowniana* occurs with few valves only, whereas *C. ophtalmica* indicates a stagnant water body (Fuhrmann, 2012). In the tufa sand (sample 10-618), *M. zimmeri* and *S. pseudobrowniana* are abundant again. The facies shift from lacustrine lime of stage III to loose tufa was possibly induced by aggradation and/or a falling lake level. In the uppermost layer of solid and loose tufa (sample 10-619) only *C. taubachensis*, *S. pseudobrowniana* and *M. zimmeri* are dominant and other species become rare, such as *P. marchica*, *P. lobipes* and *C. laevis*. The faunal assemblage points to mosses percolated by freshwater and decaying organic matter with marginal water coverage in the seeping-spring habitat IV.

FIGURE 8 Ostracod taxa from the Bilzingsleben site, photographs 1–24 by Pietrzeniuk (unpublished, modified), 1–24 transmitted light images, 25–42 reflected light images. **1–2** *Scottia pseudobrowniana*, SP 2, sample 9932. **3–4** *Microdarwinula zimmeri*, sample 10-620-C. **5–6** *Prionocypris zenkeri*, SP 3, sample 9933-C. **7–8** *Eucypris pigra*, SP 3, sample 9933-C. **9–10** *Herpetocypris brevicaudata*, SP 3, sample 9933-C. **11–12** *Herpetocypris reptans*, SP 3, sample 9933-C. **13–14** *Potamocypris zschokkei*, SP 3, sample SP 3, 9933. **15–16** *Potamocypris villosa*, SP 3, sample 9933. **17–18** *Potamocypris* sp. A, SP 3, sample 9933. **19–20** *Cypridopsis vidua*, SP 3, sample 9933. **21–22** *Cypridopsis hartwigi*, SP 3, sample 9933. **23** *Cavernocypris subterranea*, SP 3, sample 9933. **24** *Fabaeformiscandona angusta*, SP 3, sample 9933. **25–26** *Darwinula stevensoni*, sample 9195. **27–28** *Scottia browniana*, sample 9195. **29–30** *Candonopsis kingsleii*, sample C11. **31–32** *Cyprideis torosa*, sample 9191. **33–34** *Paracandona euplectella*, sample 9197. **35–38** *Limnocythere inopinata*, **35–36** female, **37–38** male, SP 11, sample 2478. **39–40** *Potamocypris fallax*, sample 9195. **41–42** *Notodromas monacha*, sample 9195. **29–30** *C. kingsleii*, sample C11 is from a sampling campaign in 2009. Scale bars 500 μm.

TABLE 2 Rare species from section 70 were documented by Diebel and Pietrzeniuk (1980) and according to collection material from the Natural History Museum Berlin (MfN).

Sample	Cryptocandona vavrai	Cypria ophtalmica	Cyprideis torosa	Cypridopsis vidua	Darwinula stevensoni	Eucypris pigra	Ilyocypris gibba	Potamocypris fallax	Pseudocandona albicans	Scottia browniana	Internal moulds
9198		•									
9197		•		•							
9196		•		•							
9195	•	•		•	•	•	•		•	•	•
9194	•						•	•	•		
9193								•	•		•
9192	•	•					•	•	•	•	•
9191	•		•				•	•			•

3.7.5 | Pit 11 (Eem Interglacial)

The ostracod fauna of pit 11 is very diverse. Among few spring-related ostracod species, such as *N. faba* and *C. subterranea* (Meisch, 2000), are species that adapted to permanent water bodies fed by springs. An interconnection of different facies zones of standing water bodies and flowing waters can be concluded because *P. zenkeri* avoids stagnant waters (Fuhrmann, 2012; Klie, 1938). The different sediments characterized by Unger (1963) as 'gastropod-marls' and 'gastropod-sands' indicate different sedimentation patterns as well. *L. inopinata* (Figure 8, 35–38) has no specific requirements on its environment and tolerates salinities over 5–18 PSU (Meisch, 2000). The amphigonic population is remarkable since male specimens are extremely rare today (Meisch, 2000).

4 | DISCUSSION

4.1 | Ostracod taxonomy and geological age

As the taxonomic scheme for this study is based on Meisch (2000), *C. ovum* and *C. taubachensis* have to be discussed in brief. Diebel and Pietrzeniuk (1984) described *C. taubachensis* from sediments of the Eemian Parkhöhle (park cave) in Weimar (Thuringia, Central Germany) and therefore distinguished *C. ovum* and *C. taubachensis* among ostracods from the Bilzingsleben site. In contrast, Meisch (2000) stated that since *C. ovum* has a considerable variability of length and shape of the carapace in lateral and dorsal views, and shows variations in the colour of the valves, several separate species were described by different authors. Because of this variability, Meisch (2000) and Matzke-Karasz (1995) assign the carapace of *C. taubachensis* to *C. ovum*. On the other hand, Fuhrmann (2012) confirms *C. taubachensis* and distinguishes the species from *C. ovum* by a prominent dorsal angle. Meisch (2000) argues that the relationship of *C. taubachensis* with *C. ovum* must be clarified by the description of the appendages. However, in this article, since the species diagrams were compiled by Pietrzeniuk and species identity is not finalized, *C. taubachensis* remains in the diagrams (Figures 4–6) and in the taxa list as a separate taxon.

Sample 9933 from pit 3 yielded a new species, *Potamocypris* sp. A (Figure 8, 17–18). This species is going to be described in a future publication.

S. browniana (Jones 1850) (Figure 8, 27–28, section 70, sample 9195), and *Ilyocypris quinculminata* Sylvester-Bradley 1973 (Figure 7, 45–48, SP 3, sample 9933), have both palaeoenvironmental and biostratigraphical value. Judging by the accompanying fauna, *S. browniana* lived in standing water bodies (Kempf, 1971). Fuhrmann (2012) states for *S. browniana* that no recent occurrence is known, and the species is probably extinct. For this reason, he characterizes it as an index fossil of the Lower and Middle Pleistocene. Besides Bilzingsleben, *S. browniana* was found only in two other localities in Central Germany: Lützensömmern and Kalbsrieth (Diebel, not published, cited by Kempf, 1971). *I. quinculminata* was found in
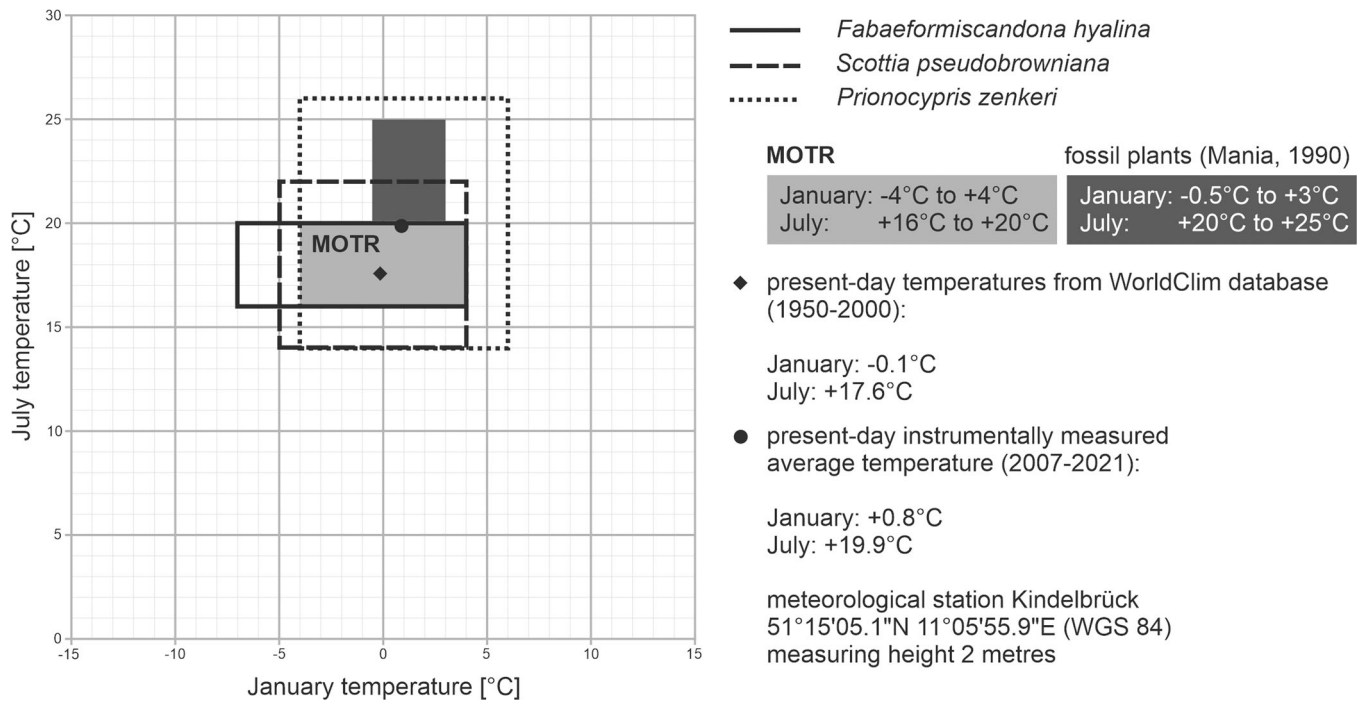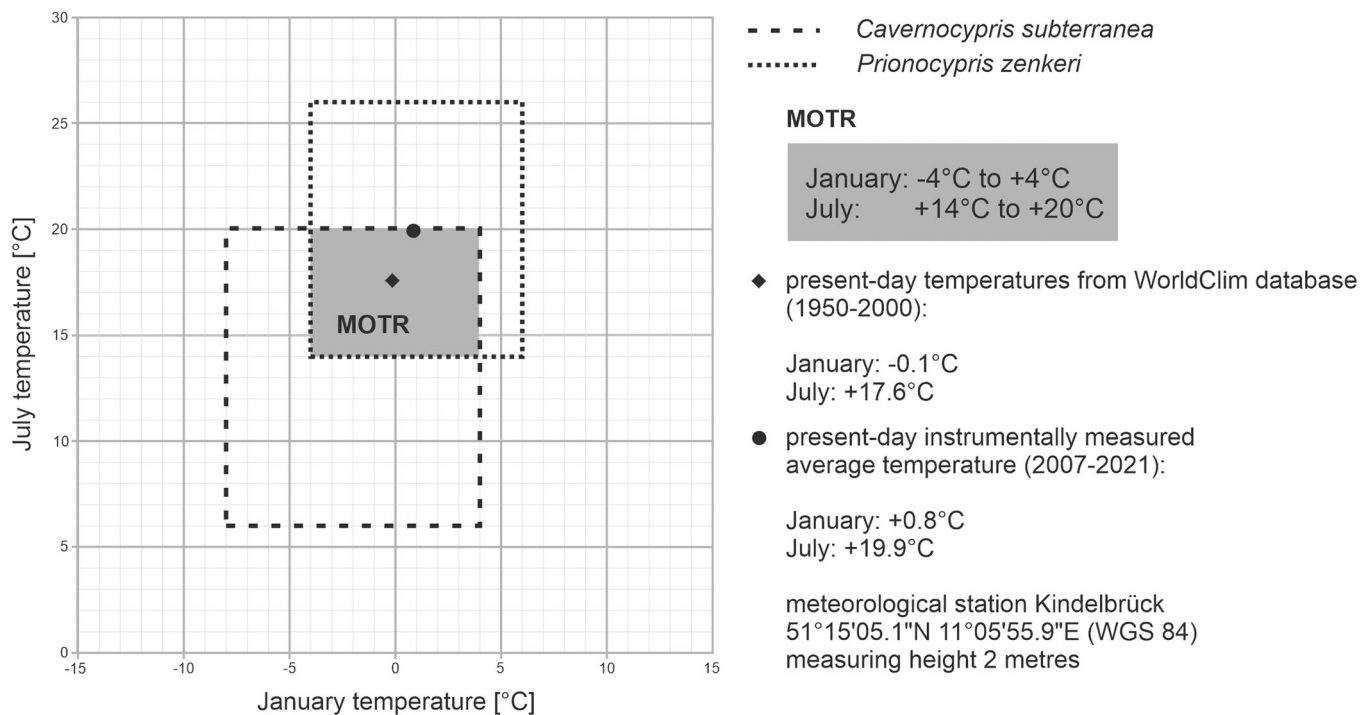
FIGURE 9 Mutual Ostracod Temperature Range (MOTR) reconstruction for the Holsteinian deposits of the Bilzingsleben site. Average air temperatures in January (x-axis): −4°C to +4°C and in July (y-axis): +16°C to +20°C (light grey rectangle). Fossil plants investigated by Mania (1990) indicate average air temperatures of −0.5°C to +3°C in January and +20°C to +25°C in July (dark grey rectangle). The WorldClim database values for Bilzingsleben are −0.1°C in January and +17.6°C in July. Recent average air temperatures were estimated at +0.8°C in January and +19.9°C in July at the nearby Kindelbrück meteorological station.

FIGURE 10 Mutual Ostracod Temperature Range (MOTR) reconstruction for Eemian fluviatile deposits at the Bilzingsleben site. Average air temperatures in January (x-axis): −4°C to +4°C and in July (y-axis): +14°C to +20°C.
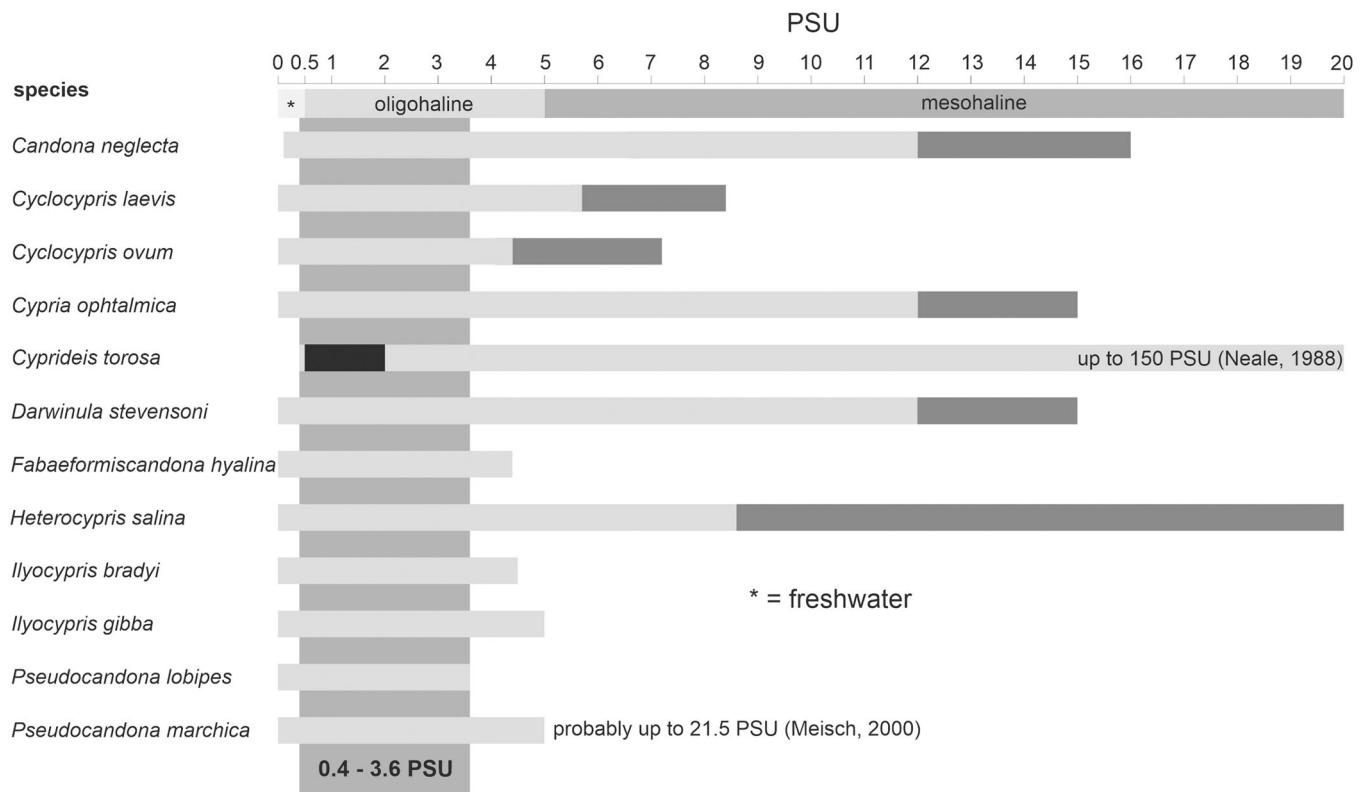
FIGURE 11 Salinity reconstruction of the Bilzingsleben site based on ostracod environmental data given by Frenzel et al. (2010) for the Baltic Sea area, Neale (1988) for *Cyprideis torosa*, and Meisch (2000), light grey bars. Further observations by the authors and/or unpublished data from third parties indicate higher salinity tolerances for some species (dark grey bars). The black bar indicates dominant populations of *C. torosa* at a salinity range from 0.5 to 2 PSU (Frenzel et al., 2010). The mutual salinity range of the Bilzingsleben site is estimated at 0.4–3.6 PSU. PSU, practical salinity units.

Wildschütz, Saxony, Germany (Fuhrmann, 1991) and by Kempf (1997) in Wohnbach near Berstadt, Hessen, Germany. Diebel and Pietrzeniuk (1980) already mentioned finds of *I. quinculminata* from the Bilzingsleben site but did not picture them. As no recent occurrence is known so far, Fuhrmann (2012) assumes that *I. quinculminata* is also extinct and therefore represents an index fossil probably of the Lower and for sure the Middle Pleistocene. According to Fuhrmann (2012), it lived in standing water bodies. Morgan (1973) assigned it to slowly flowing water with calcareous silt as sediment.

Griffiths (1995) limits the occurrence of *I. quinculminata* to the Cromerian and Hoxnian/Holsteinian, and those of *S. browniana* to the Hoxnian/Holsteinian and Saalian. Since both extinct species were found at the Bilzingsleben site, their occurrence proves the age determination of the Middle Pleistocene and Holstein Interglacial. In Central Germany, this interglacial is correlated with MIS 11 (Bittmann et al., 2018; Lauer & Weiss, 2018; Wansa et al., 2019).

4.2 | Section correlation

The section correlation (Figure 12) could be conducted based on the sediment layers, the ostracod associations and the interpreted palaeoenvironmental conditions. As with the interpretation of the

sections, this was also not always possible without a doubt, especially when the ostracod data indicated different habitats. Based on the location of the sections, their sediment layers, and ostracod assemblages, it is inferred that the location of section 362 (Figure 13), with a seeping-spring habitat and formation of tufa (IV) at its base, is probably proximal to the karstic spring and that sections 218, 171 and 70 have a more distal location with respect to the distance to the spring area. For this reason, the correlation of section 362 with sections 70, 171 and 218 is subject to uncertainties. This is expressed by mixed habitat indices I-A/IV, which may have occurred at the same time nearby. Section 171 shows a clear fluviatile setting (II) at its base with an indistinct species association and rheophilic *P. zenkeri* (Fuhrmann, 2012). Since the species assemblage of the lower part of section 70 is also indistinct to some extent, it is correlated to the fluviatile setting likewise, even though *P. zenkeri* was not found here.

At section 362 loose tufa from seeping springs (sample 10-615) was deposited in a shallow lacustrine setting with seeping-spring influx (III-A/IV). The loose tufa of section 362 can be correlated with sandy lacustrine lime of sections 218, 171 and 70 and pure lacustrine lime that precipitated in a stagnant water body (Figure 12) and mixed in places with tufa sand. Characteristic attributes of the lacustrine habitat III are the occurrences of *N. monacha*, *C. ophtalmica* and *P.*
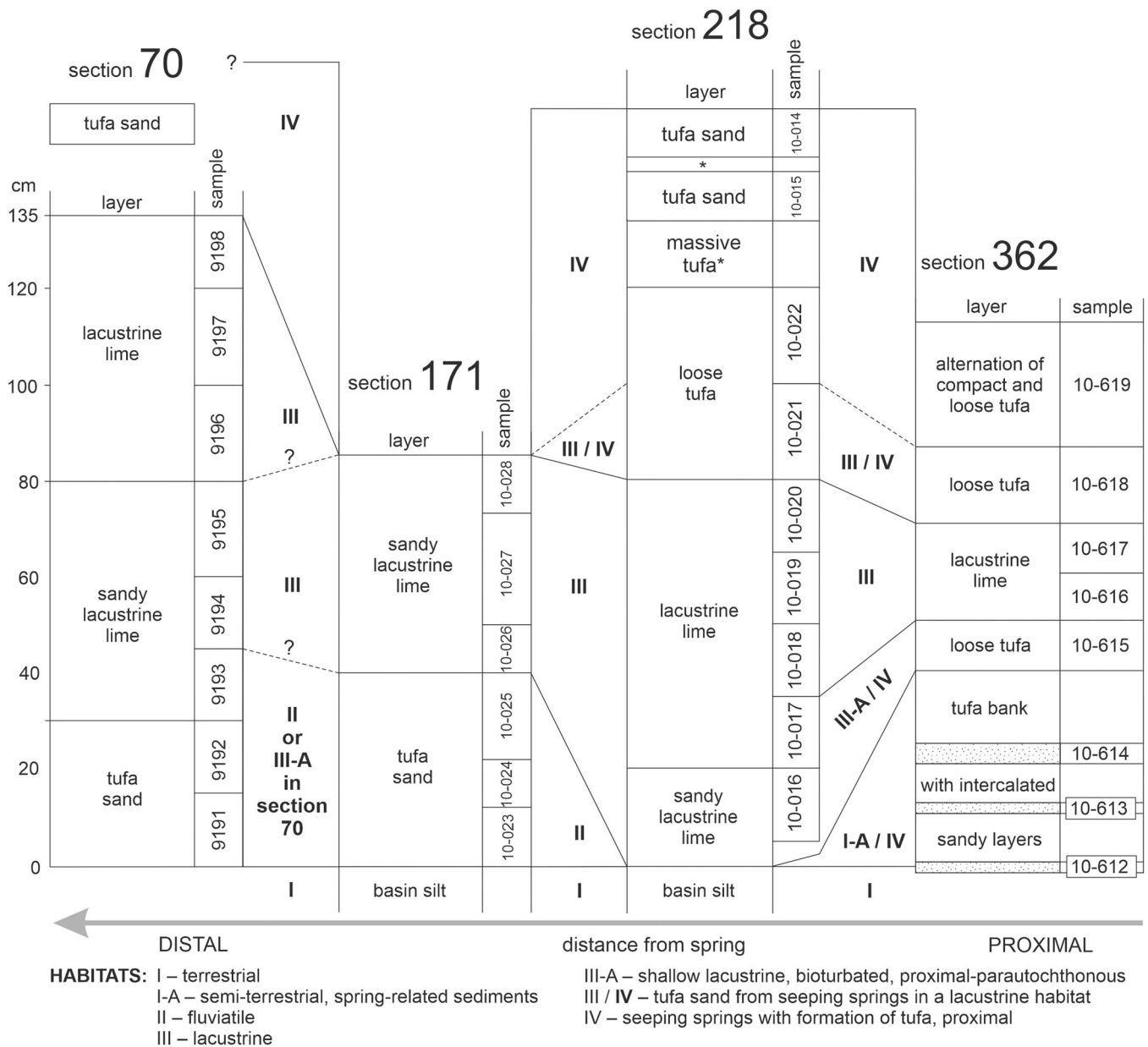
FIGURE 12 Correlation of sections 70, 171, 218 and 362 with an interpretation of habitats (bold Roman numerals).

euplectella (Meisch, 2000). The deposition of tufa sand at the top of sections 218 and 362 can be assigned to a developing seeping-spring habitat (IV). Initially, tufa sand from the spring(s) was deposited in the forming lake since the ostracod record is still diverse and species abundance is high. For this reason, a further mixing of habitats is indicated (III/IV). Later, the deposition of tufa sand increased and the seeping-spring habitat (IV) developed fully and a massive tufa bank formed due to the ongoing precipitation of tufa.

4.3 | Site development

The ostracod assemblages of the sections investigated by Diebel and Pietrzeniuk (1980, section 70) and Pietrzeniuk in the 1980s (sections 171, 218 and 362) indicate a natural development from a fluviatile to lacustrine and seeping-spring setting or, in the case of section 362, from seeping springs to lacustrine and finally seeping-spring habitats. Section 218 reflects a shallow-water environment with components from seeping springs merging into a lacustrine and then fully seeping-spring habitat. Section 171 shows a development from fluviatile to lacustrine conditions (Figure 13).

The ostracod species corroborate their facies and habitat dependence. They are reliable indicators for stratification and correlation of the sections as well as the reconstruction of the palaeoenvironments (Table 3). The fluviatile habitat (II) of sections 70 and 171 is characterized by rare valves of *P. zenkeri*. The sediments also contain numerous Mesozoic microfossils, which indicate erosion at external sediment sources and support the indication of flowing

TABLE 3 Habitat-dependent ostracod species with an interpretation of sequence phases of the Bilzingsleben site.

Sediment	Indicator species	Habitat	Sequence
Limonitic tufa sands	*Scottia pseudobrowniana, Microdarwinula zimmeri*	Seeping springs (IV) with mosses percolated by freshwater, semi-terrestrial, shallow puddles and ponds, drained by brooks, formation of tufa	Development of a massive covering tufa bank
Fine-grained tufa sands	*Fabaeformiscandona breuili, Cryptocandona vavrai,Nannocandona faba*	Springs and spring-related flowing waters with the formation of tufa (I-A)	Transition from a stagnant water body to spring-related facies and vice versa (362)
Pure lime	*Cypria ophtalmica, Notodromas monacha, Paracandona euplectella*	Stagnant water body with or without freshwater inflow, precipitation of lacustrine lime (III)	Stagnant water body with a distinct aquatic flora and fauna, mesotrophic, oxygen deficiency and increased conductivity due to evaporation
Sandy lime	*Candona neglecta, Ilyocypris bradyi, Darwinula stevensoni*	Shallow water body with an inflow of freshwater, precipitation of lacustrine lime, mixup with tufa sands (III-A)	Flooding of the site and development of a shallow stagnant water body
Sandand gravelrich in siliciclastics	*Prionocypris zenkeri*	Small river or brook (II)	Sediment accumulation in a fluviatile setting

waters. The sediment of the fluviatile habitat (II) has an allochthonous character. For this reason, the archaeological finds from these sediments are considered as probably relocated. The sediments of the brook channels incised into the basal silt (I, terrestrial) must be differentiated from the fluviatile setting. Here, orange to ochre-yellowish tufa sand was deposited. Indicator species are *M. zimmeri* and *S. pseudobrowniana* (sections 218 & 362, habitats III-A/IV and I-A/IV). Both species mirror wetlands where extensive precipitation of tufa occurred onto plants and organic detritus such as fallen leaves (Fuhrmann, 2012; Meisch, 2000). Springs and spring-related flowing waters (habitat I-A; Figures 12 and 13) are indicated by *F. breuili, C. vavrai* and *N. faba* (Meisch, 2000). As flowing water plays a significant role in these habitats, archaeological finds may also have been relocated.

The fluviatile facies (II) at sections 70 and 171 as well as the seeping-spring habitats at the base of sections 218 and 362 gradually changed into lacustrine facies II. The diversity and abundance of ostracods increased rapidly, and the associations represent a shallow, carbonate-rich lake (III-A and III) with an influx of freshwater from the springs nearby and a small river or brook. The ongoing influx of freshwater caused the mixing of lime with clastic sediment components such as tufa sand and siliciclastic sediment particles from the river or brook. Indicator species for the sandy lime (III-A) are *C. neglecta, I. bradyi* and *D. stevensoni*. Due to the ongoing transgression of the lake level authigenic carbonate precipitation increased and fewer coarse sediment components were deposited. The newly developed permanent water body (lacustrine habitat—III) is characterized by the ostracod species *C. ophtalmica, N. monacha* and *P. euplectella*. Species diversity decreased because of the deterioration of living conditions and reduction of the oxygen content of the water body. A bloom of charophytes is characteristic of this stage and recognizable by the high abundance of oospores of *C. hispida* and minor *C. vulgaris* embedded in the lime. All sections were finally

covered by a massive tufa bank with intercalated tufa sands that formed in a seeping-spring habitat (IV), documented in sections 218 and 362 but removed in sections 70 and 171 by quarry operations.

4.4 | Palaeoenvironmental conditions

The palaeo air temperature estimations of the samples obtained from the sections provide reliable temperature data. By applying the MOTR method and comparing fossil plant-based estimates, we find quite similar average temperatures as today. Horne et al. (2022) investigated the MIS 11 site Hoxne, United Kingdom, with a multiproxy consensus approach and found the following temperature values for the deposits from the temperate phases F, E and D (Hoxnian interglacial phase) during January and July: Stratum F, −8°C to −4°C and +16.0°C; Stratum E, 0°C to +3°C and 18.0–20.5°C and Stratum D, 0°C to +1°C and +16.0°C to 19.0°C. The temperature ranges of the Bilzingsleben site with −4°C to +4°C and +16°C to +20°C are similar to those of the Hoxne interglacial deposits. Applying the new multiproxy consensus approach of Horne et al. (2022) to the Bilzingsleben MIS 11 tufa deposits could provide further insights in future. It would also be interesting in future studies to see whether temperature changes can be detected in the sections that are reflected in the ostracod communities. This is also true for the estimation of the salinity of the former water body, which was classified as oligohaline at 0.4 and 3.6 PSU. However, this would require a much more refined sampling scheme and a more extensive species diagram, which the available data could not provide. The temperature determinations based on the Eemian ostracods from pit 11 can only be of orienting character. Nevertheless, the fossil temperature range includes today's average temperatures, even if the metrologically determined average July temperature of +19.9°C is almost the maximum of the ostracod-based temperature range of
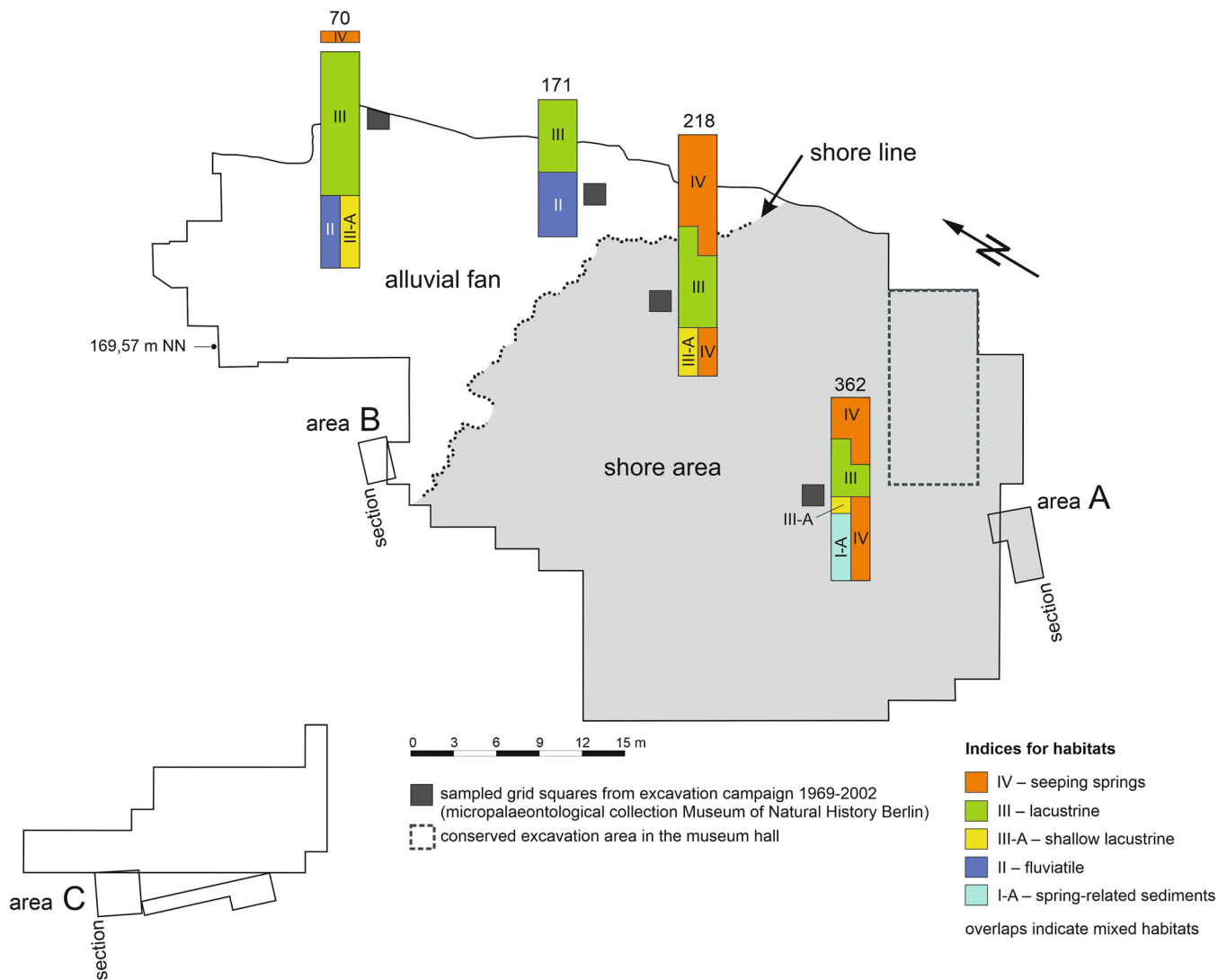
FIGURE 13 Site excavation map with the location of the examined sections 70, 171, 218 and 362 and their habitat interpretation. Compiled from Mania (1980), Mania et al. (2004) and Beck et al. (2007).

+20°C. It would be of great benefit for the reconstruction of the site development to search for these sediments and to sample and analyse them fine stratigraphically as well.

5 | CONCLUSIONS

By investigating the diverse freshwater ostracod associations of four sections and six search pits, it was possible to substantially refine the analysis of the natural development of the Bilzingsleben site. Palaeoenvironmental parameters like mean air temperature with a range of −4°C to +4°C in January and +16°C to +20°C in July point to mild winters and warm summers with temperatures similar to the present-day climate. For the Eemian deposits, a temperature range of −4°C to +4°C in January and +14 °Cto +20°C in July could be deduced. Despite uncertainties, the results point to moderate summer temperatures. The salinity of the former water body was

oligohaline and ranged between 0.4 and 3.6 PSU with some indications of allochthonous species. Furthermore, the ostracod data indicate several small-scale habitat changes, both spatially and temporally. Because of the selective investigation of four sections, the spatial information on these processes is limited but the distinction of two areas, an alluvial fan and a semiterrestrial area, can be validated. Regarding the interpretation of the archaeological record, it has to be taken into consideration that the site is substantially affected by natural processes of deposition, erosion and redeposition occurring in fluviatile, lacustrine and seeping-spring settings. Especially flowing water caused erosion and dislocation of sediment components as well as a fast burial of animal and hominin bones and played, besides numerous other factors, an important role in site formation. However, the mass flow theory which has been taken into account for the vertical scatter of archaeological finds is based on the micropalaeontological data on ostracods, unlikely for all sections investigated in this study.

For further investigations, it is essential to carry out fine-stratigraphic analyses of the preserved sections for the specification of the statements made in this study. This is especially true for the deposits on the shore area, which show a high density of finds. Further analyses could clarify to what extent the find layer, which was doubted to be in situ, was influenced by water-induced transport, resedimentation and other taphonomical processes.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ORCID

Thomas Daniel http://orcid.org/0000-0003-4530-4246

REFERENCES

Beck, M., Gaupp, R., Kamradt, I., Liebermann, C., & Pasda, C. (2007). Bilzingsleben site formation processes—Geoarchaeological investigations of a Middle Pleistocene deposit: Preliminary results of the 2003–2005 excavations. *Archäologisches Korrespondenzblatt*, *37*, 1–18.

Bittmann, F., Börner, A., Doppler, G., Ellwanger, D., Hoselmann, C., Katzschmann, L., Sprafke, T., Strahl, J., Wansa, S., & Wielandt-Schuster, U. (2018). The Stratigraphic Table of Germany 2016. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, *169*(2), 295–306.

Brasser, M. (2017). Die Megafauna von Bilzingsleben [The megafauna of Bilzingsleben]. *Veröffentlichungen des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte*, *73*, 252 [in German].

Brühl, E. (2015). Grundlegende Publikationen zu den geologischen, paläontologischen und archäologischen Forschungen auf der Steinrinne bei Bilzingsleben [Basic publications on the geological, palaeontological and archaeological research on the Steinrinne near Bilzingsleben]. In E. Brühl (Ed.), *Archaeology between the conflicting priorities of changes in climate, landscape and culture* (pp. 38–51). International Bilzingsleben Colloquium [in German].

Diebel, K. (1979). Die Ostracodenfauna der Menschenfundstelle Bilzingsleben und ihrer Umgebung [The ostracod fauna of the hominin site Bilzingsleben and its vicinity]. *Kurzreferate "Neue Ergebnisse der Paläontologie". Tagung vom 18. bis 21. April 1979 in Kühlungsborn, Gesellschaft für geologische Wissenschaften der DDR*, 24. https://www.dggv.de/wp-content/uploads/2022/08/exkursionsfuehrer_altbestaende_lapp.pdf

Diebel, K., & Pietrzeniuk, E. (1975). Ostracoden aus dem holozänen Travertin von Bad Langensalza [Ostracods from the Holocene tufa deposits of Bad Langensalza]. *Quartärpaläontologie*, *1*, 27–55 [in German].

Diebel, K., & Pietrzeniuk, E. (1977). Ostracoden aus dem Travertin von Taubach bei Weimar [Ostracods from the tufa deposits of Taubach near Weimar]. *Quartärpaläontologie*, *2*, 119–137 [in German].

Diebel, K., & Pietrzeniuk, E. (1978). Die Ostracodenfauna des eeminterglazialen Travertins von Burgtonna in Thüringen [The ostracod fauna of the Eemian interglacial tufa deposits of Burgtonna in Thuringia], *Quartärpaläontologie*, *3*, 87–91 [in German].

Diebel, K., & Pietrzeniuk, E. (1980). Pleistocene ostracods from the discovery site of the *Homo erectus* near Bilzingsleben. *EAZ—Ethnographisch-Archäologische Zeitschrift*, *21*, 26–35 [in German].

Diebel, K., & Pietrzeniuk, E. (1984). Jungpleistozäne Ostrakoden aus Sedimenten der Parkhöhlen von Weimar [Late Pleistocene ostracods from sediments of the Parkhöhlen near Weimar]. *Quartärpaläontologie*, *5*, 285–319 [in German].

Frenzel, P., & Boomer, I. (2005). The use of ostracods from marginal-marine, brackish waters as bioindicators of modern and Quaternary environmental change. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *225*(1–4), 68–92.

Frenzel, P., Keyser, D., & Viehberg, F. A. (2010). An illustrated key and (palaeo)ecological primer for postglacial to recent Ostracoda (Crustacea) of the Baltic Sea. *Boreas*, *39*(3), 567–575.

Fuhrmann, R. (1991). Ostrakoden aus den Holstein-Interglazialbecken Wildschütz und Dahlen (Sachsen) [Ostracods from the Holsteinian interglacial basins Wildschütz and Dahlen (Saxony)]. *Zeitschrift für geologische Wissenschaften*, *19*(3), 269–288 [in German].

Fuhrmann, R. (2012). Atlas quartärer und rezenter Ostrakoden Mitteldeutschlands [Atlas of Quaternary and Recent ostracods of Central Germany]. *Altenburger Naturwissenschaftliche Forschungen*, *15*, 320 [in German].

Griffiths, H. I. (1995). European Quaternary Freshwater Ostracoda: A biostratigraphic and palaeobiogeographic primer. *SCOPOLIA*, *34*, 1–169.

Griffiths, H. I., & Holmes, J. A. (2000). *Non-marine ostracods and Quaternary palaeoenvironments* (p. 179). Quaternary Research Association.

Heinrich, W.-D., & Frenzel, P. (2018). Erika Pietrzeniuk 1935–2015. *Cypris*, *32/33*, 104–110.

Horne, D. J. (2007). A Mutual Temperature Range method for Quaternary palaeoclimatic analysis using European nonmarine Ostracoda. *Quaternary Science Reviews*, *26*, 1398–1415.

Horne, D. J., Ashton, N., Benardout, G., Brooks, S. J., Coope, G. R., Holmes, J. A., Lewis, S. G., Parfitt, S. A., White, T. S., Whitehouse, N. J., & Whittaker, J. E. (2022). A terrestrial record of climate variation during MIS 11 through multiproxy palaeotemperature reconstructions from Hoxne, UK. *Quaternary Research*, *111*, 1–32.

Horne, D. J., Curry, B. B., & Mesquita-Joanes, F. (2012). Mutual Climatic Range Methods for Quaternary ostracods. In D. J. Horne, J. Holmes,

J. Rodriguez-Lazaro, & F. A. Viehberg (Eds.), *Ostracods as proxies for Quaternary climate change. Developments in Quaternary Science* (Vol. 17, pp. 2–232). Elsevier.

Horne, D. J., & Mezquita, F. (2008). Palaeoclimatic applications of large databases: Developing and testing methods of palaeotemperature reconstruction using nonmarine ostracods. *Senckenbergiana lethaea*, *88*(1), 93–112.

Kempf, E. K. (1971). Ökologie, Taxonomie und Verbreitung der nichtmarinen Ostrakoden-Gattung *Scottia* im Quartär von Europa [Ecology, taxonomy and distribution of the nonmarine ostracod genus *Scottia* in the Quaternary of Europe]. *Eiszeitalter und Gegenwart*, *22*, 43–63 [in German].

Kempf, E. K. (1997). Das mittelpleistozäne Interglazial von Berstadt [The Middle-Pleistocene interglacial of Berstadt]. *Geologische Abhandlungen Hessen*, *75*, 68–73 [in German].

Klie, W. (1938). Ostracoda, Muschelkrebse [Ostracoda, seed shrimps]. In F. Dahl (Ed.), *Die Tierwelt Deutschlands und der angrenzenden Meeresteile nach ihren Merkmalen und ihrer Lebensweise* (Vol. 34 (3), p. 230). Fischer [in German].

Lauer, T., & Weiss, M. (2018). Timing of the Saalian-and Elsterian glacial cycles and the implications for Middle–Pleistocene hominin presence in central Europe. *Scientific Reports*, *8*(1), 5111.

Liebermann, C., & Pasda, C. (2014). Silexfunde aus dem Mittelpleistozän von Bilzingsleben (Lkr. Sömmerda) [Silex finds from the Middle Pleistocene of Bilzingsleben, Sömmerda county]. *Archäologisches Korrespondenzblatt*, *44*, 443–462 [in German].

Mania, D. (1980). Die Molluskenfauna aus dem Travertin komplex von Bilzingsleben [The mollusc fauna from the Bilzingsleben tufa complex]. *Ethnographisch-archäologische Zeitschrift*, *21*, 20–25 [in German].

Mania, D. (1990). *Auf den Spuren des Urmenschen: die Funde von Bilzingsleben [Following the footsteps of prehistoric man: the finds of Bilzingsleben]* (p. 283). [Theiss, Stuttgart] [in German].

Mania, D., & Altermannn, M. (2004). Zur Geologie des altpaläolithischen Fundhorizontes von Bilzingsleben (Thüringen) unter Berücksichtigung des geologischen Wirkfaktors "Mensch" [About the geology of the Lower Paleolithic finding horizon of Bilzingsleben (Thuringia) in consideration of human impact]. *Hercynia*, *37*, 143–184 [in German].

Mania, D., & Mania, U. (2001). 30 Jahre Bilzingsleben-Forschung [30 years Bilzingsleben research]. *Praehistoria Thuringica*, *6/7*, 3–35 [in German].

Mania, D., Mania, U., Heinrich, W.-D., Fischer, K., Böhme, G., Turner, A., Erd, K., & Mai, D. H. (2004). *Bilzingsleben V, Homo erectus—seine Kultur und Umwelt, Zum Lebensbild des Urmenschen [Bilzingsleben V, Homo erectus—his culture and environment, About the life-like picture of prehistoric man]. Beiträge zur Ur- und Frühgeschichte Mitteleuropas* (p. 246). Beier & Beran [in German].

Matzke-Karasz, R. (1995). *Aktuelle Gattungs- und Artmerkmale bei Scottia, Cyclocypris, Psychrodromus und Mesocypris (Ostracoda) [Current genus and species characters of Scottia, Cyclocypris, Psychrodromus and Mesocypris (Ostracoda)]* (p. 285). [PhD thesis, Sonderveröffentlichungen des Geologischen Instituts der Universität zu Köln] [in German].

Meisch, C. (2000). Crustacea: Ostracoda. In J. Schwoerbel, & P. Zwick (Eds.), *Süßwasserfauna von Mitteleuropa* (Vol. 8, p. 522). Spektrum Akademischer Verlag.

Meisch, C., Smith, R. J., & Martens, K. (2019). A subjective global checklist of the extant non-marine Ostracoda (Crustacea). *European Journal of Taxonomy*, *492*, 1–135.

Morgan, A. V. (1973). The Pleistocene geology of the area north and west of Wolverhampton, Staffordshire, England. *Philosophical Transactions of the Royal Society of London*, *265 (Series B)*, *265*, 233–297.

Müller, W., & Pasda, C. (2011). Site formation and faunal remains of the Middle Pleistocene site Bilzingsleben. *Quartär*, *58*, 25–49.

Neale, J. W. (1988). Ostracods and palaeosalinity reconstruction. In P. De Decker, J. P. Colin, & J. P. Peypouquet (Eds.), *Ostracoda in the Earth sciences* (pp. 125–155). Elsevier.

Pasda, C. (2012). A study of rock and flints from Bilzingsleben. *Quartär*, *59*, 7–46.

Pint, A., Frenzel, P., Fuhrmann, R., Scharf, B., & Wennrich, V. (2012). Distribution of *Cyprideis torosa* (Ostracoda) in Quaternary athalassic sediments in Germany and its application for palaeoecological reconstructions. *International Review of Hydrobiology*, *97*(4), 330–355.

Pint, A., Frenzel, P., Horne, D. J., Franke, J., Daniel, T., Burghardt, A., Funai, B., Lippold, K., Daut, G., & Wennrich, V. (2015). Ostracoda from inland waterbodies with saline influence in Central Germany: implications for palaeoenvironmental reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *419*, 37–46.

Pint, A., Schneider, H., Frenzel, P., Horne, D. J., Voigt, M., & Viehberg, F. (2017). Late Quaternary salinity variation in the Lake of Siebleben (Thuringia, Central Germany)—Methods of palaeoenvironmental analysis using Ostracoda and pollen. *The Holocene*, *27*(4), 526–540.

Quante, E., Pint, A., & Frenzel, P. (2022). Nonmarine Ostracoda as proxies in (geo-)archaeology—A review. *Geoarchaeology*, *37*, 711–732. https://doi.org/10.1002/gea.21912

Unger, K. P. (1963). *Erläuterungen zur Geologischen Spezialkarte der Deutschen Demokratischen Republik 1:25.000, Blatt 4732 Weissensee [Explanations to the geological special map of the German Democratic Republic 1:25.000, map 4732 Weissensee]*. Zentrales Geologisches Institut (ZGI) [in German].

Vlček, E. (2002). *Der fossile Mensch von Bilzingsleben [The fossil man of Bilzingsleben]. Bilzingsleben VI* (p. 392). Beier & Beran [in German].

Wansa, S., Strahl, J., & Rappsilber, I. (2019). Zur Geologie des Ummendorfer Kessels im oberen Allertal—Forschungsbohrung Ummendorf 1/2012 [On the geology of the Ummendorf Basin in the upper Allertal valley—Research borehole Ummendorf 1/2012]. *Mitteilungen zu Geologie und Bergwesen von Sachsen-Anhalt*, *20*, 206 [in German].