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Pre-LGM loess deposits in caves of Polish Jura – occurrence and stratigraphic importance

A review paper

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ABSTRACT:

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Loess is an important component of cave deposits. Loess and loess-like strata in caves and rock shelters may serve as stratigraphic correlative units and paleoclimate indicators. For the Polish Jura (southern Poland), one of the key regions of cave deposits studies in Europe, the published information concerning the stratigraphic importance of loess is limited to the sequences from around the Last Glacial Maximum (LGM). In this paper, a review of the archival data about loess deposits situated below the LGM strata in caves and rock shelters of the Polish Jura is presented. The paper discusses the occurrence, lithology, stratigraphy, chronology and paleoecology of the pre-LGM cave loess. The most important sites of the pre-LGM cave loess in the region include: Biśnik Cave, Nietoperzowa Cave, Mamutowa Cave, and Ciemna Cave (only the outer zones). The loess strata in these sites correlate with cold Marine Isotope Stages (MIS): mid-3, 4, 5b–d, 6, and possibly 10. They represent all the main facies of cave loess: typical eolian loess, colluviated loess-like deposits, loess with bedrock debris, and loams of complex grain-size composition but with the predominance of a loess component. Stratigraphic correlations with loess-paleosol sequences are proposed.

Key words: Cave deposits; Loess; Stratigraphy; Pleistocene; Kraków-Częstochowa Upland; Poland.

I dedicate this paper to Professor Leszek Lindner, who taught me the art of Quaternary stratigraphy.

INTRODUCTION

Loess is among the most characteristic deposits of the Pleistocene age. Currently, this type of sediment accumulates in limited zones of the world, but not in Europe (Derbyshire *et al.* 1998; Ložek 2021). Therefore, it has no direct actual representation in the European continent and must be regarded there as a fossil record of currently absent conditions, which are commonly interpreted as being a cold and extremely arid continental climate of a periglacial or desert zone (Pye 1995; Wright 2001; Muhs and Bettis 2003; Dlussky 2009; Jary 2009; Łanczont *et al.* 2023). Loess strata therefore make good marker horizons, recording periglacial periods. Loess profiles – containing also intercalated deposits, such as paleosols and solifluction layers – have been used for nearly a century as key logs for the Quaternary stratigraphy in Europe, Asia and North America (e.g., Kukla 1987, 1975; Lindner 1991; Dodonov and Baiguzina 1995; Shackleton *et al.* 1995; Maruszczak 1996; Frechen and Yamskikh 1999; Lindner *et al.* 2002; Jary 2007; Antoine *et al.* 2013; Łanczont and Madeyska 2015; Marković *et al.* 2015; Dzierżek and Lindner 2020; Lehmkuhl *et al.* 2021). An advantage of studying loess is that a wide spectrum of dating methods can be applied for these sediments, including lithostratigraphy, pedostratigraphy, luminescence (TL, OSL, IRSL) dating, magnetostratigraphy, biostratigraphy (based e.g., on mollusks), and in some cases tephrochronology, radiocarbon dating and archaeological dating (Beer and Sturm 1995; Maher *et al.* 2002; Lang *et al.* 2003; Roberts 2008, 2015; Dlussky 2009; Antoine *et al.* 2013; Łanczont and Madeyska 2015; Ložek 2021).

However, besides this huge stratigraphic potential, the direct correlation of loess profiles with other types of sediments (e.g., lacustrine, bogs, fluvial, glacial) is rather limited. This is partially due to the rarity of interlayering between loess and sediments of other environments, which is an effect of the elevated topographic situations where loess typically occurs – on the tops and slopes of hills. And it is partially due to the different climatic conditions that favored accumulation of loess and of other types of sediments, which often resulted in diachronic accumulation. There are few sedimentary environments that coalesce the depositions of loess and other types of sediments at the same place, and one of them is the cave environment. Several facies of sediments are known from the near-entrance parts of caves and rock shelters, such as: fluvial deposits, speleothems, rockfall debris, colluvial deposits, biogenic and anthropogenic accumulations, and also loess-like sediments (Bosch and White 2004; White 2007; Mallol and Goldberg 2017). Many caves, being sediment traps, have collected sediments continuously for long time intervals (e.g., Ford 1988; Goldberg and Macphail 2013), both during the periods of periglacial conditions (i.e., when loess could have accumulated) and during more humid and/or warm times (when other types of sediments were deposited). This has created a potential for gathering and preserving interstratifications of loess with other sediments, and has produced sequences that are of great correlative importance.

In Poland, among several regions with karst phenomena, the best studied in terms of the lithology and stratigraphy of cave fills is the Polish Jura, also known as the Kraków-Częstochowa Upland. Variable cave sediments are widely known from caves and rock shelters in this region (Madeyska 1981, 1988; Madeyska and Cyrek 2002). The presence of loess and loess-like sediments was commonly noticed (e.g., Krukowski 1939; Madeyska-Niklewska 1969; Madeyska 1981, 1988; Kowalski 2006; Krajcarz *et al.* 2012, 2014, 2020; Wilczyński *et al.* 2020; Kot *et al.* 2022a). The best preserved and known are loess deposits from around the Last Glacial Maximum (LGM), mentioned from numerous sites. The stratigraphy of cave loess and loess-like deposits of LGM chronology was comprehensively presented in the review of Krajcarz *et al.* (2016). However, cave loess deposits of younger (i.e., post-LGM) and older (i.e., pre-LGM) chronologies remain underemphasized in the literature. In this review I focus on the pre-LGM loess in caves. The goal of this paper is to collect all archival data about the occurrence of pre-LGM loess and loess-like deposits in caves and rock shelters of the Polish Jura, and to provide a critical evaluation and remarks on the usefulness of such strata as correlative horizons.

MATERIAL AND METHODS

This paper is intended as a review of archival and literature data. The research method was search of the literature and critical evaluation of published data. The most important sources of information are those publications that present the lithology and stratigraphy of cave deposits with long profiles and complex stratification. These include monographic studies of sediments of caves and rock shelters, mostly resulting from archaeological excavations. The key references are: Krukowski (1939); Madeyska-Niklewska (1969); Madeyska (1981, 1988, 1992); Cyrek *et al.* (2000); Kowalski (2006); Mirosław-Grabowska (2002a); Nadachowski *et al.* (2009); Krajcarz *et al.* (2014); and Valde-Nowak *et al.* (2014).

Terminology

In this paper I focus on the near-entrance facies of cave sediments, which is defined here after Kukla and Ložek (1958) as sediments which accumulated under the direct impact of external environmental conditions (such as climate, weather, atmospheric processes, biological activity). Such sediments occur around cave openings, as well as several meters towards the cave interior and usually also several meters in front of the cave (where they represent the original deposits laid down inside the cave, followed by later exposure due to a partial collapse of the cave walls and roof). Such situations are known as *denuded caves* or *unroofed caves* (Šušteršič 2007).

The term ‘loess’ is used in this paper in a wide sense, as an umbrella term for any sediments of predominantly silty grain-size composition, yellowish macroscopic appearance, predominance of quartz and feldspar in a mineral composition, typically with the presence of carbonates, of variable compaction and cementation state, and of polygenetic origin. This approach follows the definitions of loess *sensu* *lato* (Pésci 1990; Smalley and Jary 2004; Jary 2007). Several facies can be distinguished among loess defined in this way, including typical eolian loess, re-deposited loess-like accumulations underneath slopes, alluvial loess etc. The term '*cave loess*' is used here after Krajcarz *et al.* (2016) for such widely understood loess that occurs in the near-entrance parts of caves and rock shelters. This is a similar term to *Höhlenlöss* used by other authors (e.g., Prošek and Ložek 1957; Frank 1990). According to Krajcarz *et al.* (2016), three main facies are known among LGM *cave loess* deposits in the caves of the Polish Jura:

Type 1: Typical loess – composed of silty material, yellowish, massive or with weakly marked sub-horizontal lamination. This type may be interpreted as being of eolian origin and fills the narrow definition (*sensu stricto*) of loess (e.g., Pye 1995; Follmer 1996).

Type 2: Loess with rock debris – material of bimodal grain-size distribution, whose one component is silt similar to typical loess, and another is gravel and boulders composed of the local bedrock material, which most usually is a massive Oxfordian limestone. Sedimentary structures are usually not visible; however, a common textural feature is a gradual upward or downward decrease of the amount and size of gravel/boulder clasts. This type fits to the sediment group of *lessoids* defined by Pye (1987).

Type 3: Re-deposited loess – clearly laminated silty material, sometimes with intercalations of another material (such as sand and humus) and with normal grading within laminas; sometimes these sediments fill erosional channels. Such deposits may be interpreted as a result of colluvial or proluvial action, in particular, sheet-wash or concentrated linear erosion followed by accumulation in a temporary stream, and fills the definition of *loess-like deposits* provided by Ložek (2021).

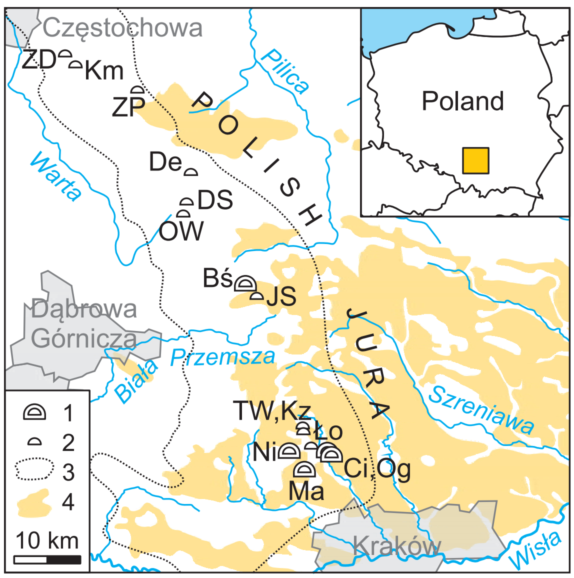
Along with the above, one more type of cave deposit shares some similarities with loess and loess-like deposits *sensu lato*:

Type 4: Silty loams – massive diamictons composed of co-occurring fractions of silt, clay, sand, gravel, and sometimes also boulders, usually with the predominance of silt and gravel components, with grain size composition typical of loams (according to the terminology of the US Department of Agriculture), or silts/clayey silts/silty coarse clays/silty medium clays (according to EU standard EN-ISO 14688). This type is very common in the near-entrance facies of cave fills and is sometimes referred to as a 'cave loam' or 'loessy loam' (Madeyska 1981, 1982b). It resembles type 2 (loess with debris), but differs by having a higher amount of clay, greater cohesion, alteration of limestone clasts (rounding, smoothing), and sometimes darker color and content of humus. Sediments of such textural characteristic may result from a combination of many sedimentary agents (such as: eolian deposition; rock fall and further physical disintegration of clasts; chemical weathering; infiltration and illuviation; biogenic accumulation; see Madeyska 1981, Nejman *et al.* 2017). Therefore, they should be thoroughly regarded as a variant of a *cave loess* only if the silt component clearly predominates and any distinct traces of other sedimentary environments are lacking.

RESULTS

Occurrence of pre-LGM *cave loess*

In contrast to the LGM series of *cave loess* that is common in caves and rock shelters of the Polish Jura (Krajcarz *et al.* 2016), the occurrence of pre-LGM *cave loess* was confirmed in only a few sites (Text-fig. 1). The list of caves that undoubtedly host the pre-LGM *cave loess* is limited to: Biśnik Cave, Nietoperzowa Cave, Mamutowa Cave, Ciemna Cave, and Ogrójec near Ciemna Cave. Disputed, weakly preserved or



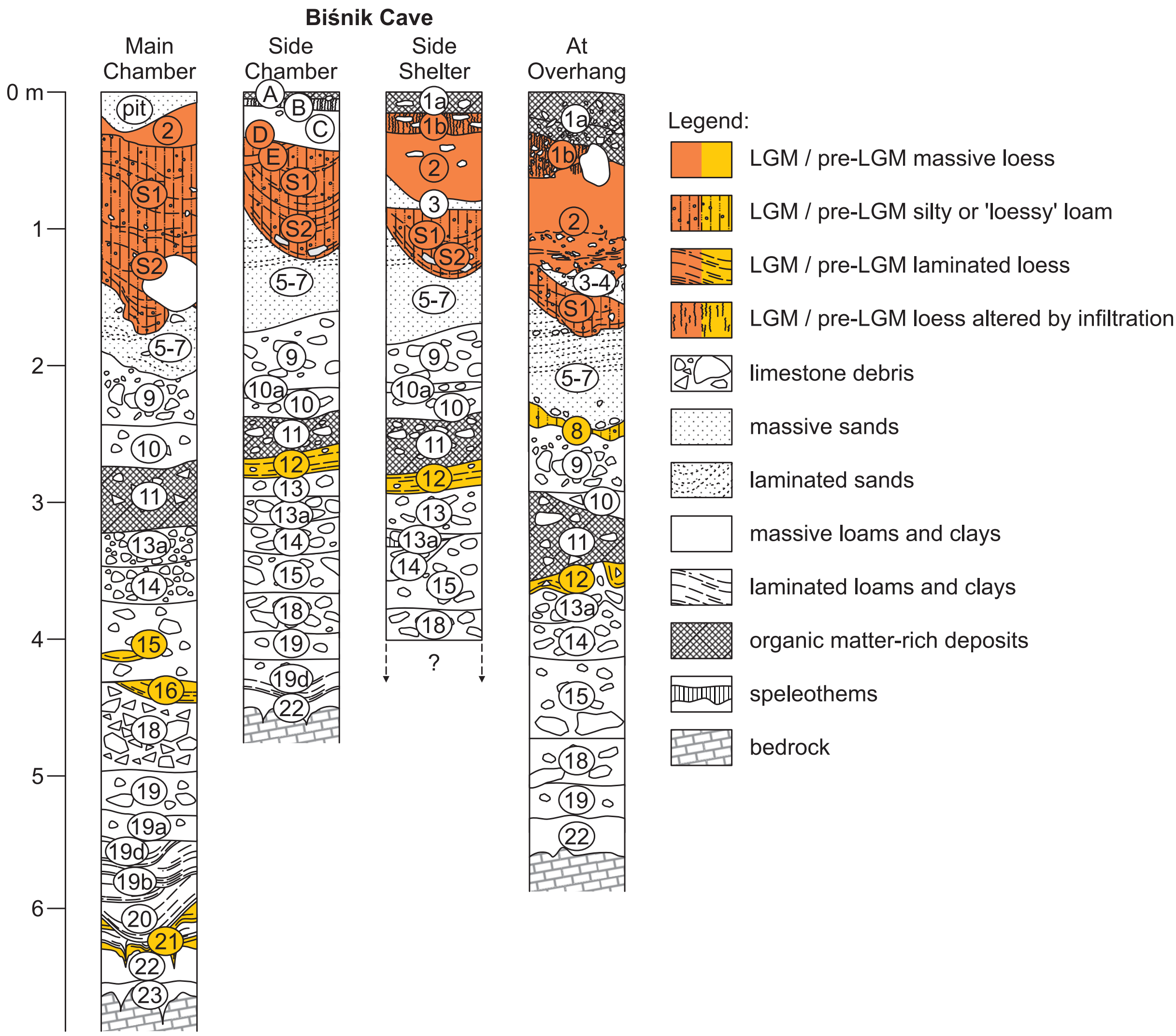
Text-fig. 1. Location of cave sites with pre-LGM loess deposits: 1 – the main sites (Bś – Biśnik Cave, Ci – Ciemna Cave, Ma – Mamutowa Cave, Ni – Nietoperzowa Cave, Og – Ogrójec); 2 – other sites (De – Deszczowa Cave, DS – Dziadowa Skała Cave, JS – Jasna Strzegowska Cave, Km – Komarowa Cave, Kz – Koziarnia Cave, Ło – Łokietka Cave, OW – Cave in Okiennik Wielki, TW – Tunel Wielki Cave, ZD – Zamkowa Dolna Cave, ZP – Caves II and III in Złoty Potok); 3 – Polish Jura (Kraków-Częstochowa Upland); 4 – distribution of loess.

weakly documented records possibly are also known from: Deszczowa Cave, Dziadowa Skała Cave, Jasna Strzegowska Cave, Komarowa Cave, Koziarnia Cave, Łokietka Cave, and Tunel Wielki Cave.

Biśnik Cave

Biśnik Cave is the most important site in terms of the pre-LGM *cave loess* stratigraphy. Within its >6 m long profile of sediments there are at least four strata of loess deposits preserved in superposition below the LGM series (Text-fig. 2, see also Krajcarz *et al.* 2016). The lithology and stratigraphy of the Biśnik Cave sediments was presented in several monographic papers (Mirosław-Grabowska 2002a, 2002b; Krajcarz *et al.* 2014) and here I summarize these descriptions.

The uppermost of the pre-LGM *cave loess* units in Biśnik Cave is Layer 8. Unfortunately, this stratum has been entirely excavated in the course of archaeological work and is no longer available for examination. J. Mirosław-Grabowska described it as single lenticles of yellow-brown sandy silts, with a relatively high content of sand, which is typical for the entire Weichselian (the Last Glaciation) part of the Biśnik Cave sequence (Mirosław-Grabowska 2002a; Krajcarz *et al.* 2014). Resistant (48%) and medium resistant (48%) minerals (groups I and II *sensu* Chlebowski *et al.* 2002) predominate within the heavy mineral fraction. This points toward long transport or re-worked source material (Chlebowski and Lindner 1992; Chlebowski *et al.* 2002). The associated fauna is typical of tundra or steppe-tundra en-



Text-fig. 2. Simplified litho-stratigraphic logs of the Biśnik Cave sedimentary sequence (after Krajcarz *et al.* 2014, modified). Loess strata marked by colors.

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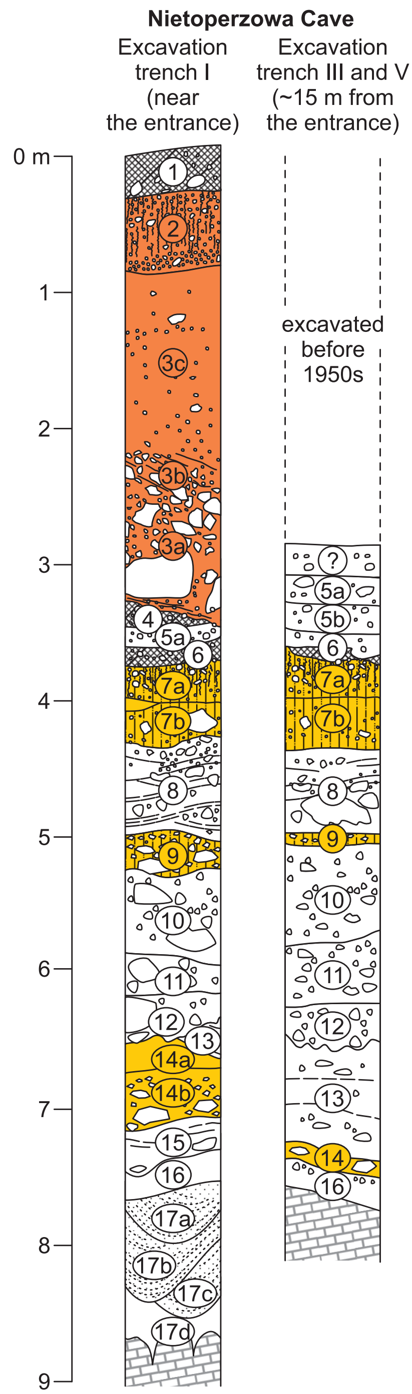
vironment. The U-Th dates for bones are unequivocal: 79±9 and 199±22 ka (Hercman and Gorka 2002). Its general stratigraphic position allows the correlation of the layer with the Lower Pleniglacial of the Weichselian, or MIS 4 (Krajcarz *et al.* 2014).

Separated from Layer 8 by a ~1 m-thick packet of dark humiferous loams is another loess stratum, named Layer 12. It is a yellow-brown sandy loam or loamy sand, composed of alternate loess and sandy laminas, and some laminas of humus. This structure together with the general dip toward the cave interior points towards re-deposition by running water. The stratum is widespread across the cave, but in the external part (so called ‘The Overhang’) it is spatially divided into several discontinuous irregular lenses (Mirosław-Grabowska 2002a), likely due to later cryoturbation (Krajcarz *et al.* 2014). Medium resistant (63%) and resistant (35%) minerals predominate, indicating lengthy transport or re-worked source material. The fauna is of mixed steppe-tundra – forest ecological affiliation. The OSL and TL dating places the deposition of Layer 12 about 110–90 ka BP, while the U-Th dating of bones places it between ~50 and ~100 ka BP (Gąsiorowski *et al.* 2014; Hercman 2014). Together with its general stratigraphic position and location just above the paleomagnetic Blake Event (see Krajcarz *et al.* 2014), the dating points toward the early part of the Weichselian, i.e., MIS 5b–5d, the most likely MIS 5d.

Loess sediments occur also in the form of small and thin lenses in the lower part of Layer 15 and a thin lens directly below it (then regarded as a separate Layer 16; Krajcarz *et al.* 2014). This is a weakly laminated silt or silty loam. The concave shape of the lenses’ bottoms points towards linear erosion and re-deposition of loess material from another place. The presence of several lenses in different altitudinal positions suggests multiple re-deposition events. The mineral composition has not been studied yet. Due to the limited size of the lenses, only a few animal remains were connected with these strata. There is one OSL date for Layer 16, Lub-5469, that is 159.0±9.2 ka BP (Krajcarz *et al.* 2014). This date is in accordance with the U-Th dating of the directly overlying Layer 15, that is between ~90 and ~150 ka BP (Hercman 2014).

The fourth and the lowest occurrence of loess deposits in Biśnik Cave is within Layer 21. This stratum is weakly known as it was excavated in a very limited area of 3 m^2. The primary structure of this layer is hard to reconstruct due to secondary disturbances in the form of (desiccation?) cracks and bending. However, a complex composition of alternating thin (1–2 cm) laminas of yellowish to gray (gleied) silt and reddish clay is clear. This rhythmic lamination may be interpreted as a record of multiple events of alternate re-deposition of loess and *terra rosa*-like clay. The silty component of Layer 21 was OSL-dated to 370±20 ka BP, Lub-5470 (Krajcarz *et al.* 2014). No animal remains are known from this stratum.



Text-fig. 3. Simplified litho-stratigraphic logs of the Nietoperzowa Cave sedimentary sequence (after Madeyska-Niklewska 1969, modified). Symbols and colors are explained in the Text-fig. 2.

Nietoperzowa Cave

The second key site is Nietoperzowa Cave. Three strata of loess deposits were identified here in superposition below an almost 4-m thick LGM series (Text-fig. 3). A description of the lithology and a proposal of the chronostratigraphy was provided by Madeyska-Niklewska (1969).

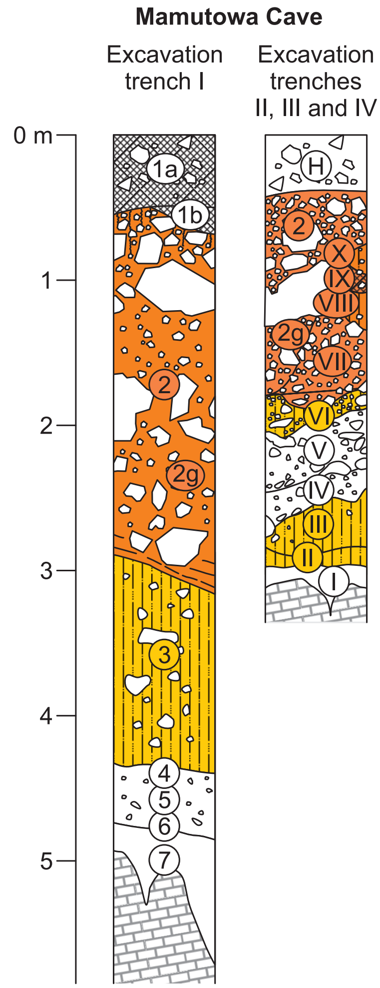
The uppermost pre-LGM *cave loess* occurrence here is Layer 7. It is a complex series. The lower part, named Sublayer 7b, is a yellowish-brown silty loam with sparse limestone clasts. Upward, within Sublayer 7a, the amount of limestone clasts gets higher, their size lower, and the color becomes darker toward grayish-brown due to infiltration from the overlying organic-rich deposits of Layers 4–6. A thin lens of pure loess was found inside the stratum near the cave entrance. The entire series has a continuous and quite large thickness of ~1 m in the entire excavated area. Radiocarbon dating of bones from Layer 7 gave unequivocal results; however, it suggests an age between ~45 and ~40 ka, i.e., a middle part of MIS 3 (Krajcarz *et al.* 2018).

Layer 9 consists of limestone debris with pale gray silty-loamy matrix. In front of the cave the boulders of the debris reach a diameter of 1 m. The thickness is greatest in front of the cave (70 cm) and decreases down to 20 cm toward the cave interior. Traces of frost heave were noticed. The stratigraphic position allows for correlation with the Lower Pleniglacial (MIS 4), which is consistent with radiocarbon dating of the overlying series, indicating the age of Layer 9 being >50 ka (Krajcarz *et al.* 2018).

Layer 14 forms a continuous stratum of loess with a high amount of angular limestone clasts in the lower part (Sublayer 14b), and nearly pure yellowish loess of aggregative texture in the upper part (Sublayer 14a). The general thickness decreases toward the cave interior from ~1.3 m near the entrance down to 20 cm inside, while the thickness of Sublayer 14a decreases both towards the cave interior and outward. Flint artifacts found here have dulled edges, indicating some abrasion, likely by eolian corrasion. According to its stratigraphic position, Madeyska-Niklewska (1969) correlated this stratum with the late part of the penultimate glaciation (Odranian, or MIS 6), and its uppermost parts possibly with the beginning of the Eemian Interglacial (MIS 5e).

Mamutowa Cave

Two series of loess-like strata are known from Mamutowa Cave (Text-fig. 4). A description of the lithology and stratigraphy was provided by Madeyska (1992). The upper series was situated immediately below the thick and complex LGM loess series. It comprised silty loam of Layer 3 in the entrance zone and Layer VI in the central part of the cave, rich in faunal remains of mixed ecological characteristics (Nadachowski 1976). Its pre-LGM age is suggested by several radiocarbon dates within ~44–32 ka BP (Wojtal 2007; Lorenc 2013).



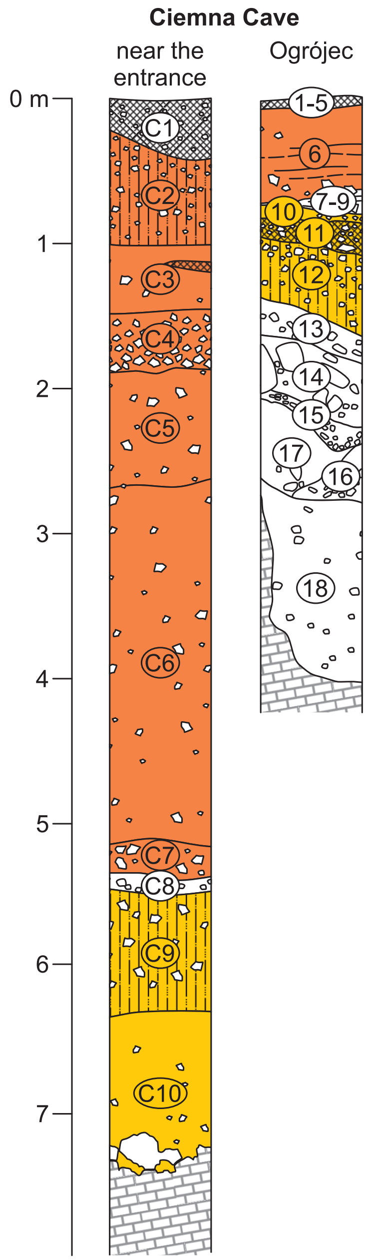
Text-fig. 4. Simplified litho-stratigraphic logs of the Mamutowa Cave sedimentary sequence (after Madeyska 1992, modified). Symbols and colors are explained in the Text-fig. 2.

The lower series was found only in the central part. It was separated from the upper one and from the LGM series by several reddish clayey loams. Its lower part, called Layer II, was a yellowish-brown silty loam, and the upper part, Layer III, was a gray silty loam with quite numerous animal bones. The series was up to 1 m thick and at many places it lays directly on the bedrock or within the bedrock cracks. Faunal remains in these strata represent a tundra ecosystem (Bocheński 1974; Nadachowski 1976). The general stratigraphic position suggests the middle MIS 3 or MIS 4 chronology. Radiocarbon dating of bones from the overlying sediments (Wojtal 2007) indicates that the age of the series is close to or beyond the radiocarbon limit (which is ~55 ka BP, Reimer *et al.* 2013), and thus, points toward MIS 4 chronology.

Ciemna Cave and Ogrójec

Loess deposits were found in several separated archaeological excavation zones in Ciemna Cave and at the plateau in front of the cave. Near the current entrance of Ciemna Cave, a 2-m thick sequence of two strata was found at a depth below 5.5 m (Text-fig. 5, see also Krukowski 1939). Unfortunately, the sediments were excavated a long time ago (in 1918–1919) and are no longer available due to backfilling and degradation of the excavation pit. The lower part of the sequence, called Layer C10, was a pale brown unlaminated calcified loess with sparse angular limestone clasts. The upper part, called Layer C9, was a pale reddish-brown silty loam with abundant limestone debris. The boundary between the strata was gradual. These sediments contained several lithic artifacts and bones of tundra mammals. S. Krukowski (1921) correlated these strata with the penultimate glaciation. However, later revision based on archaeological material and lithostratigraphic correlations rather inclines toward the MIS 4 chronology (Valde-Nowak *et al.* 2014, 2016).

Ogrójec, a wide plateau between Ciemna Cave and Oborzysko Wielkie Rock Shelter, is currently an open-air site (Gradziński *et al.* 2020); however, its localization between two caves, the presence of typical cave deposits (clayey loams with limestone debris and animal bones), and the morphology of the limestone walls around the site suggest that in the past it was a part of a cave that has been exposed due to massive rock fall. A sequence of three loess strata was found here (Text-fig. 5, see also Krukowski 1939; Kowalski 2006). The description of the lithology and stratigraphy was provided by Madeyska (1981). As in the Ciemna Cave entrance zone, the sediments are no longer accessible after the excavations finished in 1968. The sequence, being ~80 cm thick, starts from Layer 12, which is a pale brown silty loam with slightly weathered fine limestone clasts, sparse in its lower part. It passes upward into a dark gray loess with slightly weathered fine limestone clasts, called Layer 11. The gray coloration is connected with burnt bones (Wojtal 2007). The sequence was topped with Layer 10, a pale loess with slightly weathered limestone debris. The series contained a rich archaeological lithic assemblage with Levallois technique and the presence of Prądnik-type bifaces, which is classified as the Micoquian cultural unit of the Middle Paleolithic (Valde-Nowak *et al.* 2014). Two radiocarbon dates (Poz-25261 and Poz-27268) allow the middle part of this series to be placed between ~47 and ~41 ka BP (Valde-Nowak *et al.* 2014), i.e., the middle part of MIS 3.



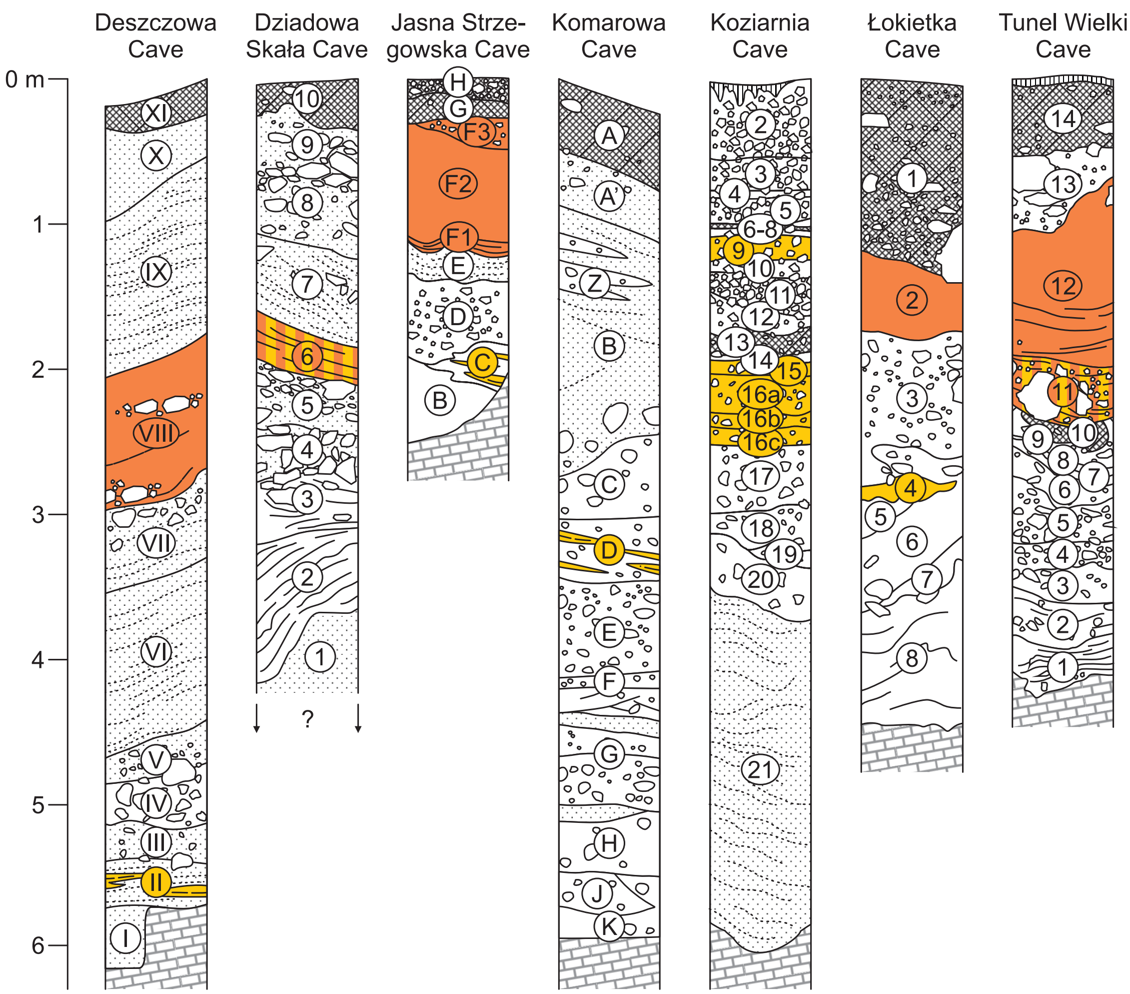
Text-fig. 5. Simplified litho-stratigraphic logs of the Ciemna Cave and Ogrójec sedimentary sequences (after Krukowski 1939; Kowalski 2006; Valde-Nowak *et al.* 2016; modified). Symbols and colors are explained in the Text-fig. 2.

Other sites

In Tunel Wielki Cave, laminated sediments of complex lithology were found in Layer E (*sensu* Kot *et al.* 2022a), representing Layer 11 *sensu* Madeyska (1988; see Text-fig. 6). This colluvial/proluvial series contains variable material mixed together, including aggregates of loess-like material of unknown age and Middle Pleistocene clayey loams with fossil bones (Kot *et al.* 2022a). Unfortunately, it lacks precise dating and its general stratigraphic position only allows setting it between MIS 2 and MIS 12.

In Dziadowa Skała Rock Shelter, Layer 6 (Text-fig. 6) was characterized as a stratum of laminated loess (Chmielewski 1958; Dylik *et al.* 1954). No dates are available for this layer, but it was generally associated with Interpleniglacial of the Weichselian, i.e., MIS 3, on the basis of general stratigraphic position and the weathering state of limestone clasts (Madeyska 1981). However, considering that a series of radiocarbon dates obtained for the directly overlying strata shows quite young results (between ~15 and ~12 ka BP, Lorenc 2013), the LGM age seems considerable.

In Koziarnia Cave, two series possibly related to pre-LGM loess-like deposits were noticed (Madeyska-Niklewska 1969). These include: Layer 9 (pale yellow loam with limestone debris) and Layers 16c–16b–16a–15 (pale yellow loams with limestone debris in the upper part, separated by a cultural level, see Text-fig. 6). In the original publication, the ages of these two series were assumed to be Weichselian mid-Interpleniglacial (mid-MIS 3), Lower Pleniglacial (MIS 4) and Early Weichselian's second cold stage (MIS 5b). However, a more recent revision based on radiocarbon dating places all the strata mentioned within MIS 3 (Berto *et al.* 2021; Kot *et al.* 2021).



Text-fig. 6. Simplified litho-stratigraphic logs of other cave sites with pre-LGM loess (after: Chmielewski 1958; Madeyska-Niklewska 1969; Madeyska 1988; Cyrek *et al.* 2000; Lipecki *et al.* 2000; Mirosław-Grabowska and Cyrek 2009; Nadachowski *et al.* 2009; modified). Symbols and colors are explained in the Text-fig. 2. Striped yellow-orange color is for uncertain chronology position of loess (LGM or pre-LGM).

In Komarowa Cave, intercalations of horizontally and diagonally laminated silt, found within loamy Layer D (Text-fig. 6), may be interpreted as washed-in loess material. These sediments were dated to late MIS 3 on the basis of radiocarbon dating (Lorenc 2013; Nadachowski *et al.* 2009).

From Deszczowa Cave, T. Madeyska (in Cyrek *et al.* 2000) described intercalations of silts within yellow sands of Layer II (Text-fig. 6) that may be cautiously linked with colluviated or washed-in loess material. The chronology of this stratum was found to precede the Eemian Interglacial and most likely it should be linked with MIS 6 (Krajcarz and Madeyska 2010). The sparsity of loess strata in the relatively long sequence of Deszczowa Cave reflects a general lack of loess in the Kroczyce Rocks microregion, as well as the generally sandy facies of cave deposits there (Cyrek *et al.* 2000; Szymanek *et al.* 2016).

In Łokietka Cave, J. Mirosław-Grabowska (in Lipecki *et al.* 2000) described a stratum of light brown loess with limestone debris of variable morphology (called Layer 4, Text-fig. 6), situated below the loess of Layer 2 that likely represents the LGM. This stratum was generally dated by her to belong to the early part of the Weichselian, but the absence of any dating results makes this chronology uncertain.

From Jasna Strzegowska Cave, J. Mirosław-Grabowska (in Mirosław-Grabowska and Cyrek 2009) reported a stratum of laminated silts and clays (Layer C, Text-fig. 6) that formed intercalations, intrusions, and lenses of irregular bodies. These sediments may represent the alternate fluvial or proluvial deposition of loess and clay eroded from two different sources. A pre-LGM age seems likely due to the stratum's stratigraphic position below the clayey loam underlying the LGM loess, but the exact age is unknown.

Limited information about the occurrence of silty deposits in caves comes from early and mid-20 century excavations in the northern part of the Polish Jura. In Cave in Okiennik Wielki S. Krukowski found a stratum of silt situated below the complex series with a Middle Paleolithic assemblage (Krukowski 1921). This stratigraphic position allows the linking of the layers with the general pre-LGM chronology. From Złoty Potok microregion, at least from Cave II in Złoty Potok and Cave III in Złoty Potok, he also reported a thick and complex series of silts, whose stratigraphic position is uncertain (Madeyska 2009). In Zamkowa Dolna Cave, a thick packet of loess with limestone debris and a Middle Paleolithic assemblage was found, which likely may be of pre-LGM age (Kopacz 1975).

DISCUSSION

Regional occurrence

The occurrence of pre-LGM *cave loess* in the Polish Jura, according to current knowledge, is limited to several sites. This is not surprising, because there are only a few known sites with sedimentary profiles reaching down below the LGM deposits, and far fewer with preserved pre-MIS 3 deposits. Noteworthy is that most of the sites with preserved Middle Pleistocene and/or lower part of the Upper Pleistocene are also the sites of the pre-LGM *cave loess*. Among the few exceptions are: Ciemna Cave (the inner part of the chamber) and karst sites in Draby, where long sequences lack loess strata. All these sites were, however, only partially excavated, so their stratigraphic complexity is not fully recognized. This observation suggests that pre-LGM *cave loess* should be regarded as a rather common sedimentological phenomenon, not preserved, however, at many sites due to later erosion or unusual local conditions preventing any sedimentation.

Sedimentary processes

All the lithological types of *cave loess* that were identified within the LGM series (Krajcarz *et al.* 2016; see also section Terminology in Material and Methods) occur also in pre-LGM *cave loess*, however, rarely within a single series. Typical eolian loess (type 1) is rare among the pre-LGM sequences. The only examples are known from Sublayer 14a in Nietoperzowa Cave, Layer C10 in Ciemna Cave, and Layers 11–10 in Ogrójec near Ciemna Cave. More common is type 2, which is a loess with debris of the bedrock. Such deposits may form the entire loess series, e.g., Layer 9 in Nietoperzowa Cave or Layer II in Mamutowa Cave, and then they have loamy groundmass, which makes a sediment similar to type 4 (silty loams with debris). Type 2 may occur nearby type 1, either below it (Sublayer 14b in Nietoperzowa Cave), above (Layer C9 in Ciemna Cave), or sandwiching the eolian loess between two layers of loess with debris (Layers 10 and 12 in Ogrójec and Layer 7 in Nietoperzowa Cave). Similarly to the LGM series, the pre-LGM eolian deposition of loess, being a main sedimentary process or accompanied by a rockfall, was the most intense right near the cave opening. This is recorded in the greatest thickness of types 1, 2 and 4 around the cave opening, decreasing or disappearing toward the cave interior. Such situations are clearly visible in Nietoperzowa Cave in Layers

9 and 14, whose thicknesses are reduced ~5 times at the 15-m distance toward the cave interior. An even more extreme situation can be observed in Ciemna Cave, where the 2-m thick series of Layers C10–C9 situated just in front of the cave has no analogue at all inside the cave (Krajcarz and Madeyska 2013; Valde-Nowak *et al.* 2014, 2016). In Koziarnia Cave, where the sediments were studied quite far from the entrance, the loess-like deposits are represented by types 2 and 4, i.e., those with minimum input of eolian accumulation.

A more complex issue is the formation of loess deposits of type 3. These are common among the pre-LGM *cave loess*. They were found in several stratigraphic positions in Biśnik Cave (Layers 21, 16, 12 and within Layer 15), in Tunel Wielki Cave (Layer E), possibly in Deszczowa Cave (within Layer II) and Komarowa Cave (within Layer D). Lamination and interbedding with sand or clay indicate good sorting and separation of grain-size fractions, which may point toward episodic and recurrent water actions, e.g., sheet-wash. This may be the case of Layers 21 and 12 in Biśnik Cave, Layer E in Tunel Wielki Cave, and silty intercalations known from Deszczowa Cave, Komarowa Cave and Jasna Strzegowska Cave. Recognizing the exact sedimentary process needs, however, more detailed studies, such as parameters of grain size composition or micromorphological characterization. Such studies were limited in the pre-LGM *cave loess*, as well as in caves of the Polish Jura in general. A few exceptions are micromorphological studies of Layer 12 in Biśnik Cave (Krajcarz and Krajcarz 2019) and Layer E in Tunel Wielki Cave (Kot *et al.* 2022a), conducted by the author of this paper. These analyses revealed the presence of lamination, clay balls and isolated aggregates of loamy material, and separation of sand and silt. All these features are a record of water action. Another situation regards concave-bottom lenses of weakly laminated silt, connected with Layers 16 and 15 and possibly also Layer 8 in Biśnik Cave. In these cases, the deposition of silt was preceded by linear erosion, likely by a temporary stream. Loess material was then transported along these channels and deposited therein.

Chronology

The quality of chronological data regarding the pre-LGM *cve loess* varies from site to site and from stratum to stratum. In general, chronostratigraphy may be based on two types of data. The first is the stratigraphic position of a given stratum, which in many cases allows only for a wide chronostratigraphic attribution. This method commonly exploits climatostratigraphic data, derived e.g., from the weathering state of limestone clasts or fossil bones (Madeyska-Niklewska 1969, 1971; Madeyska 1981, 1992; Mirosław-Grabowska 2002a; Krajcarz *et al.* 2014; Valde-Nowak *et al.* 2014) and from the ecological requirements of those animals whose remains are preserved in the sediments (e.g., Madeyska 1981, 2009; Cyrek *et al.* 2000, 2010; Mirosław-Grabowska 2002a; Nadachowski *et al.* 2009; Socha 2014), as well as lithostratigraphy (e.g., Madeyska-Niklewska 1969; Madeyska 1981; Krajcarz *et al.* 2014). This method is, however, vulnerable to oversimplification of stratigraphic complexity due to the presence of hiatuses and the similarity of units of variable age but deposited in similar climatic conditions.

The second approach is chronology based on absolute dating methods. These include mostly luminescence techniques (OSL, IRSL and TL), radiocarbon dating, and in few cases also U-Th dating. Chronological data available for neighboring strata may be, of course, helpful also in stratigraphic dating. Chronological data have variable importance. Radiocarbon and U-Th dates usually come from fossil bones or teeth, which – in the case of re-deposited colluvial/fluvial sediments – may not be synchronous with the final deposition of the loess stratum (see also discussion in the section Paleoecology). Luminescence dates on the other hand reflect the moment of the last exposure of clastic material to sunlight. Such a date can be regarded as close to the final deposition age in the case of typical (eolian) loess or the eolian fraction of complex sediments, but in the case of re-deposited material the date may represent a residual age, i.e., the age of the original eolian deposition, which is presumably older than the final deposition (King *et al.* 2013; Poręba *et al.* 2013). The magnetostratigraphic method has been used only occasionally (Krajcarz *et al.* 2014).

An additional method is archaeological dating, based on the presence of archaeological cultures whose chronology has been widely accepted (Madeyska 1981, 1982b; Cyrek and Madeyska 2002). However, the usefulness of this method is limited to sites with well-preserved archaeological assemblages, and usually is ambiguous for the Middle Paleolithic (Cyrek and Madeyska 2002; Kowalski 2006; Cyrek *et al.* 2014; Valde-Nowak *et al.* 2014). Another method is biostratigraphy, which is usually limited to mammals and also is of restricted usefulness (Nadachowski 1982; Nadachowski *et al.* 2009; Cyrek *et al.* 2000; Berto *et al.* 2021; Kot *et al.* 2022a;).

On the basis of all available chronological data, considering the remarks presented above, five pre-LGM phases of loess accumulation in caves and rock shelters of the Polish Jura can be distinguished. These include (starting from the earliest):

Phase 1: Re-deposition of loess-like material recorded in Biśnik Cave, Layer 21. OSL date 370±20 ka BP (which correlates with MIS 10) may be regarded as being close to the original eolian deposition somewhere outside of the cave, considering that the sediments were found in quite a dark part of the cave, shadowed from sunlight, and likely the cave was even darker in the past (assuming collapse of some near-entrance parts of the cave roof, see Mirosław-Grabowska 2002a; Cyrek *et al.* 2010, 2014; Krajcarz *et al.* 2014). Final deposition inside the cave must have happened before MIS 7 (Krajcarz *et al.* 2014).

Phase 2: Deposition of eolian loess together with limestone debris from rock falls, followed by the deposition of typical eolian loess, as recorded in Nietoperzowa Cave, Layer 14. The loess material was then transported to caves, as seen in Biśnik Cave, Layers 16 and 15, and in Deszczowa Cave, intercalations within Layer II. In Biśnik Cave, the OSL date 159±9 ka BP is likely indicative for the initial eolian deposition, which can be correlated with MIS 6, or the Odranian glaciation (*sensu* Lindner and Marks, 2012; Marks *et al.*, 2016). The general stratigraphic position and chronological data for the neighboring strata (Gąsiorowski *et al.* 2014; Hercman 2014; Krajcarz *et al.* 2014) point toward final deposition inside the cave soon after, during late MIS 6 and/or early MIS 5e.

Phase 3: Re-deposition of sandy loess-like material recorded in Biśnik Cave, Layer 12. A number of OSL and TL dates are available, ranging between ~110 and ~90 ka BP, all sampled in a part of the cave quite exposed to sunlight, so the dates may represent both the original eolian deposition, or some exposure during the re-deposition. Paleomagnetic data indicate the record of the Blake Event in the directly underlying strata (Krajcarz *et al.* 2014) that is connected with the MIS 5e–MIS 5d transition, and which allows the placing of the moment of the re-deposition of loess-like material around MIS 5d.

Phase 4: The next stage, that may be correlated with the Lower Pleniglacial or MIS 4, is recorded in several sites: Biśnik Cave, Layer 8; Nietoperzowa Cave, Layer 9; Ciemna Cave, Layers C10–C9; and Mamutowa Cave, Layers II–III. All these cases document deposition of loess along with intense rock fall, likely resulting from the frost-inducted physical disintegration of the bedrock.

Phase 5: The last pre-LGM stage of loess deposition appeared during the middle part of the Weichselian Interpleniglacial, in mid-MIS 3. Such deposits are recorded in Nietoperzowa Cave, Layer 7, supported by a number of radiocarbon dates for bones from this stratum, as well as from the strata below and above (Krajcarz *et al.* 2018). The sequence there represents two periods of simultaneous accumulation of loess and rock fall debris, separated by an interval of purely eolian deposition (Madeyska-Niklewska 1969). The loess deposition history during MIS 3 in Koziarnia Cave and Ogrójec near Ciemna Cave was also complex, resulting in several strata of limestone debris and loess-like loams, interlayered with cultural levels (Valde-Nowak *et al.* 2014; Kot *et al.* 2021). In Komarowa Cave, there are possible traces of further re-deposition of loess material. In Biśnik Cave, the respective section of the sequence is reduced (Mirosław-Grabowska 2002a; Krajcarz *et al.* 2014).

At most sites, the mid-MIS 3 *cave loess* is topped with brown or reddish loams and cultural layers linked with Jerzmanowician or Gravettian archaeological materials (Cyrek and Madeyska 2002; Kot *et al.* 2021) and covered by the LGM loess series.

Paleoecology

Paleoecological information for the pre-LGM *cave loess* in the Polish Jura is limited. There is almost no data on paleovegetation, while published information about fauna is restricted to some sites. The literature data are also of variable quality regarding the number of analyzed fossils, the taxonomic groups covered by the studies, and the stratigraphic resolution of the reporting.

Reconstruction of paleoecology for loess, especially in caves, is challenging. The bases for such interpretations are the fossil remains of organisms preserved in the sediments. In contrast to loess deposits from open-air sites and to the LGM series in caves, in the pre-LGM *cave loess* mollusks are rarely noticed. The most common fossils there are those of mammals and, in rare situations, birds (Madeyska 1981, 1982b; Nadachowski 1988, 1989; Wojtal 2007; Nadachowski *et al.* 2009; Stefaniak and Marciszak 2009; Tomek *et al.* 2012; Socha 2014). Being relatively large, mammalian bones or teeth could not have been deposited by the same sedimentary process that was responsible for the accumulation of the silty material of loess, regardless as to whether it was primary eolian deposition or secondary re-deposition, e.g., by sheet-wash. Thus, the deposition of bones and loess material in many cases was or might have been diachronous, i.e., the bones were deposited earlier on the cave floor to be later covered by silt. Therefore, bone assemblages from *cave loess* must be regarded with caution, as bones in such contexts may constitute a residual material of older chronology, or even palimpsests representing variable paleoecologies.

Nevertheless, the available data for the pre-LGM *cave loess* clearly point towards a tundra or steppe-tundra ecosystem. The most common fossils belong to such animals as: reindeer (*Rangifer tarandus*), horse (*Equus* sp.), arctic fox (*Vulpes lagopus*); among rodents there are lemmings (*Dicrostonyx torquatus*, *Lemmus lemmus*), narrow-headed vole (*Lasiopodomys anglicus*), and voles of wider ecological tolerance (*Alexandromys oeconomus*, *Microtus agrestis,* and *M. arvalis*; Nadachowski 1976, 1988, 1989; Madeyska 1981, 1982b; Wojtal 2007; Nadachowski *et al.* 2009; Stefaniak and Marciszak 2009; Socha 2014). Among rare birds the black grouse (*Lyrurus tetrix*) and ptarmigans (*Lagopus* sp.) were noticed (Tomek *et al.* 2012). The presence of a forest fauna and the quite commonly reported cave bear (*Ursus spelaeus/ingressus*), noticed e.g., from Biśnik Cave, Layers 8 and 12, Nietoperzowa Cave, Layers 7 and 14, or Mamutowa Cave, Layers II and III, may result from the residual character of bone accumulations. In Komarowa Cave, a large number of cave bear and cave hyena (*Crocuta crocuta*) bones in stratified Layer D (Nadachowski *et al.* 2009; Wojtal 2007) may reflect complex sedimentation processes and a long time of deposition. A rare situation, but ecologically meaningful, is the occurrence of steppe-tundra megafauna taxa: wooly mammoth (*Mammuthus primigenius*), wooly rhinoceros (*Coelodonta antiquitatis*) and muskox (*Ovibos moschatus*). Remains of these mammals were found in: Nietoperzowa Cave, Layers 9 and 14; Ciemna Cave, Layer 11; Łokietka Cave, Layer 4; and Komarowa Cave, Layer D (Wojtal 2007).

Some the pre-LGM *cave loess* strata are poor in animal remains. Such a situation was observed in: Deszczowa Cave, Layer II; Łokietka Cave, Layer 4; Dziadowa Skała Cave, Layer 6; Ciemna Cave, Layer 10 (Wojtal 2007). It is likely that these situations are the best representations of the loess accumulation periods: the observed faunal scarcity may reflect climate deterioration and periglacial conditions, while the tundra fauna either has a residual character (its deposition preceded the loess accumulation), or represents intervals between loess deposition events. This hypothesis seems likely in the light of reconstructed quantitative environmental conditions (Socha 2014), that are rather milder than expected for the periglacial zone. In Biśnik Cave, the climatic parameters inferred from the taxonomic composition of rodent assemblages are for Layer 8: mean annual temperature +3.3°C, total annual precipitation 972 mm; and for Layer 12: +1.4°C and 914 mm, respectively (Socha 2014). These calculations may deviate toward the giving of too warm and too humid results due to the artificial inclusion of residual fauna coming from earlier periods.

Archaeology

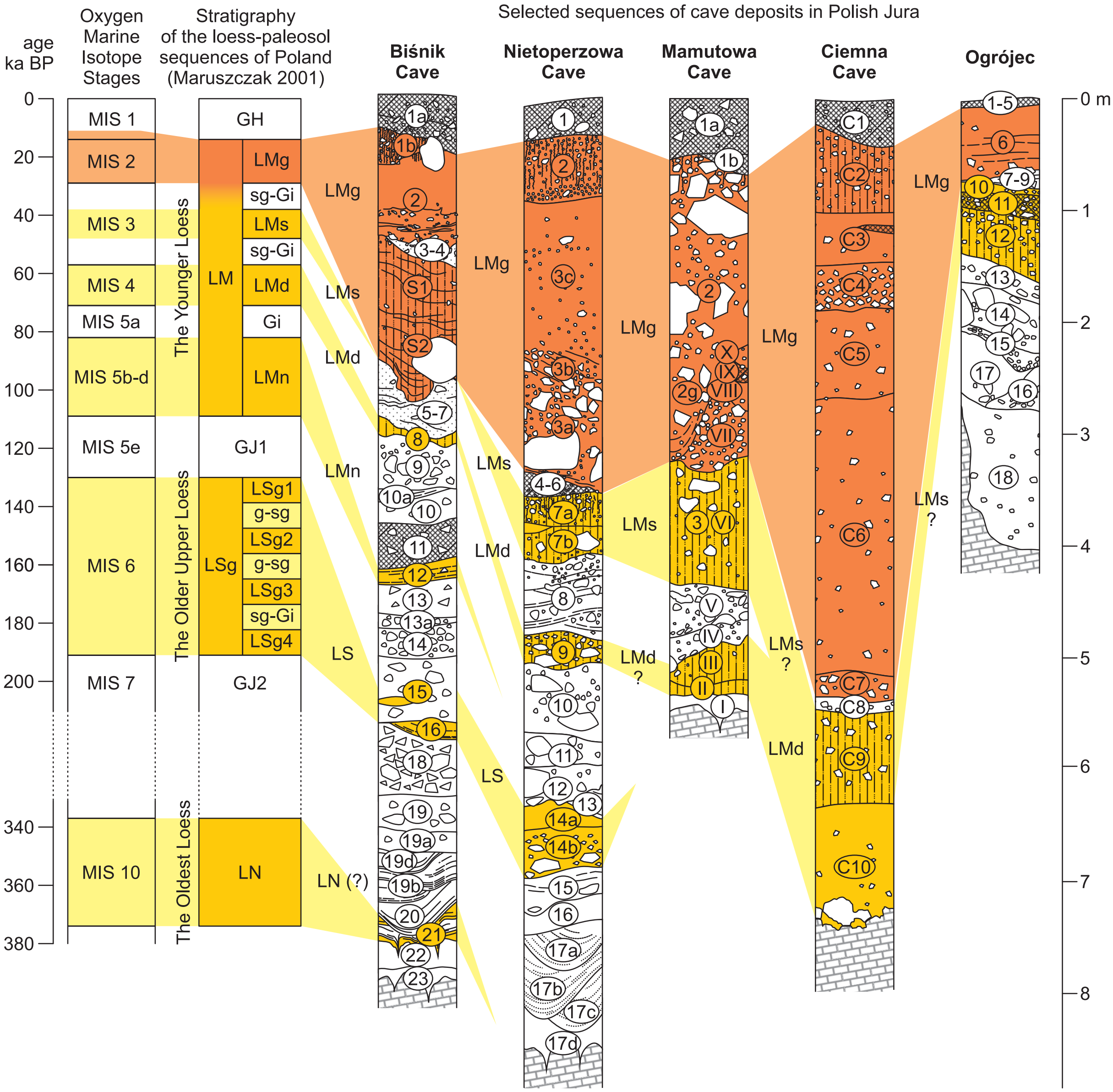
In contrast to the LGM series, the pre-LGM *cave loess* rarely contains archaeological material. The richest assemblage was found in Ogrójec near Ciemna Cave, in Layer 11 dated to MIS 3. It was a cultural level of Middle Paleolithic with Prądnik-type bifaces (Krukowski 1939; Kowalski 2006), attributed to the Micoquian tradition (Valde-Nowak *et al.* 2014). Apart from lithics, the level contained a large number of fragmented and burnt bones, and the dust of charred bones that gave the layer a dark color (Wojtal 2007). Another Micoquian level was identified in the base of Layer 12.

Another site with quite rich archaeological material is Biśnik Cave, Layer 12. This assemblage also contained bifaces in the form of leaf-shaped blades and microlithic hand-axes, along with the Levallois technique, and was attributed to the early Micoquian (Cyrek *et al.* 2010, 2014). The numerous charcoals and charcoal dust found within this stratum were possibly re-deposited from the underlying level of fireplaces (Cyrek *et al.* 2014). Other pre-LGM *cave loess* strata yielded only sparse archaeological material at best, generally linked with the Middle Paleolithic (Cyrek and Madeyska 2002; Wojtal 2007).

In Mamutowa Cave, a quite rich Jerzmanowician assemblage was found in Layer VI (Nadachowski 1976; Kowalski 2006). In another site of this archaeological unit, Nietoperzowa Cave, several Jerzmanowician cultural horizons were found, however, between the pre-LGM and LGM loess series (Chmielewski 1961; Madeyska-Niklewska 1969).

Correlation with loess-paleosol stratigraphy

The importance of searching for correlations between loess-paleosol and cave sequences was highlighted by Madeyska (1982b, 2002). Successful attempts were undertaken several times (e.g., Cyrek and Madeyska 2002; Łanczont and Madeyska 2015; Krajcarz *et al.* 2016), including the direct correlation between the sequence of Nietoperzowa Cave and that of the Kraków-Zwierzyniec loess-paleosol sequence



Text-fig. 7. Stratigraphic correlation between the Polish loess-paleosol stratigraphic scheme (Maruszczak 2001) and the sequences of the main pre-LGM *cave loess* sites in Polish Jura (compiled from: Krukowski 1939; Madeyska-Niklewska 1969; Madeyska 1992; Kowalski 2006; Krajcarz *et al.* 2014; Valde-Nowak *et al.* 2014). Orange color is for LGM and yellow for pre-LGM loess strata. Other symbols are explained in the Text-fig. 2.

(Madeyska 1982b). However, these works were focused either on archaeological issues or the LGM series, so the pre-LGM *cave loess* sequences attracted limited attention.

The schemes of loess-paleosol stratigraphy in Poland proposed by H. Maruszczak and J. Jersak (Jersak 1973; Jersak *et al.* 1992; Maruszczak 1996, 2001) are widely accepted (Lindner 1991; Jary 2007; Łanczont and Madeyska 2015; Dzierżek and Lindner 2020). The correlation of the pre-LGM *cave loess* strata with H. Maruszczak's and J. Jersak's schemes of loess-paleosol stratigraphy in most of the main sites presents no difficulties (Text-fig. 7). All main lithostratigraphic units of loess from open-air sites are present at cave sites of the Polish Jura. It indicates that caves and rock shelters, or their direct vicinities, provided a conducive environment for loess accumulation. The following stages of loess-paleosol stratigraphy can be recognized among the pre-LGM *cave loess* in the Polish Jura:

Phase 1: H. Maruszczak's Oldest Loess, possibly stage LN1 or one of the upper stages, is recorded in Biśnik Cave, Layer 21, confirmed by OSL dating. This is the only known occurrence of such an old loess in the caves of the Polish Jura.

Phase 2: H. Maruszczak's Older Loess, stage LSg. This pre-Eemian loess of MIS 6 age was found up to the present date only at three sites: Biśnik Cave (Layer 16 and several small lenses inside Layer 15), Nietoperzowa Cave (Layer 14), and Deszczowa Cave (silty intercalations within Layer II). The only certain correlation, proved by OSL dating and a well-established stratigraphic position, is for Biśnik Cave.

Phase 3: H. Maruszczak's Lowermost Younger Loess, stage LMn, or J. Jersak's Younger Loess I, can be correlated with the re-deposited loess of Layer 12 in Biśnik Cave. This stratum was well dated to the post-Eemian part of MIS 5, most likely MIS 5d.

Phase 4: H. Maruszczak's Lower Younger Loess, stage LMd, or J. Jersak's Younger Loess IIa, dated to the Lower Pleniglacial of the Weichselian, finds its pre-LGM *cave loess* equivalents in Biśnik Cave (Layer 8), Nietoperzowa Cave (Layer 9), Mamutowa Cave (Layer 3 or its correlative, Layer VI), and Ciemna Cave (Layers C10–C9). While in Biśnik Cave this stage is weakly represented, in Nietoperzowa Cave and Ciemna Cave the loess of this stage is developed in the form of a complex series of significant thickness.

Phase 5: The last pre-LGM loess stage, i.e., H. Maruszczak's Middle Younger Loess, LMs, is the most common stage of the pre-LGM *cave loess* in the Polish Jura. Deposits of this stage are known from Nietoperzowa Cave, Ogrójec near Ciemna Cave, Mamutowa Cave, Komarowa Cave, and Koziarnia Cave. Sediments of this stage represent all four sedimentological types of cave loess, which most likely results from the best preservation state of this youngest series.

The Upper Younger Loess *sensu* H. Maruszczak, or Younger Loess IIb *sensu* J. Jersak, is the equivalent of the LGM *cave loess*, widespread in caves and rock shelters of the Polish Jura, and characterized elsewhere (Krajcarz *et al.* 2016). Paleosols from open-air profiles are lacking in caves. Instead, in caves and rock shelters between the *cave loess* units there are complex series of variable polygenetic sediments, most usually weakly stratified loams with limestone debris. In contrast to the open-air sites, in caves and rock shelters the inter-loess series are thicker than loess packets. Based on this, we may conclude that loess deposition played only a minor role in the accumulation of cave fills.

The regional stratigraphy of loess-paleosol sequences in the Polish Jura is weakly recognized. In general, three units of loess separated by soils are known (Madeyska 1982a; Różycki 1982; Bednarek *et al.* 1985). These are: weakly preserved ${}_{1}Q_{p}3$ loess of pre-Eemian (MIS 6) age, up to 3 m thick, known from Siedliska; compacted and decalcified ${}_{1}Q_{p}{}^{1}4$ loess situated above the Eemian–Early Weichselian pedocomplex (likely of MIS 4 age), up to 4 m thick, known from Biała Błotna and Wilgoszcz; and the thickest and most widely distributed ${}_{1}Q_{p}{}^{2}4$ loess of LGM age, separated from the above-mentioned by an interstadial soil. This situation corresponds with J. Jersak's schemes, but is simpler than H. Maruszczak's scheme and also than *cave loess* stratigraphic complexity. The main source of material for loess in the Polish Jura were the sandy fluvioglacial deposits of the Middle Pleistocene (Chlebowski and Lindner 1975).

Inter-regional correlations

Over-regional correlation of the pre-LGM *cave loess* in the Polish Jura can be made with loess-paleosol sequences from other regions. This follows the correlations of the Polish loess-paleosol stratigraphic schemes (Jersak 1973; Maruszczak 2001) with sequences known from neighboring countries (Frechen *et al.* 1997; Frechen 1999; Thiel *et al.* 2011; Antoine *et al.* 2013; Łanczont and Madeyska 2015; Marković *et al.* 2015; Lehmkuhl *et al.* 2021). Such correlations were presented among others by: Maruszczak (1996); Lindner (1991); Lindner *et al.* (2002); Jary (2007); Łanczont and Madeyska (2015).

Correlation of the pre-LGM *cave loess* in the Polish Jura with cave deposits in other regions is difficult. This is mostly due to the limited elaboration of cave deposit lithostratigraphy outside of the Polish Jura. In Poland, the two other most important karst regions, i.e., Tatra Mts. and Sudetes Mts., lack both regional lithostratigraphy and well-recognized stratotypes of cave sediments. Beyond Poland, the neighboring regions with broadly studied cave sediments are Moravian Karst (Moravia, Czech Republic), Bohemian Karst (Bohemia, Czech Republic), Franconian Jura (Bavaria, Germany), and Swabian Jura (Baden-Württemberg, Germany). Unfortunately, the Swabian caves rarely host sequences that reach down below the MIS 3 chronology (Goldberg *et al.* 2003; Miller 2015). Among Franconian caves, the long sequence is known from Sesselfelsgrotte (Freund 1968; Richter 2001; Rots 2009). Its complex series of silty loams and rock fall debris of Layers F–R may correlate with MIS 3 and MIS 4 pre-LGM *cave loess* in Polish Jura.

In Bohemian Karst the pre-LGM loess-like deposits are weakly preserved, possibly an effect of later erosion (Kukla and Ložek 1958); however, the entire fine fraction of non-loess cave deposits is interpreted to derive among other from loess deposits (Nejman *et al.* 2017). A unique exception is cave C-718 in the Koněprusy complex, where several strata of loess in superposition were identified within the lower Middle Pleistocene part of the sequence (Prošek and Ložek 1957). Cryoturbated loess-like sediments situated below the LGM series were also reported from several caves in Slovakia, possibly of MIS 3 age, in particular Dzeravá Skala Cave, Großen Cave in Jasov, Čertova pec Cave, and Prepoštská Cave (Prošek and Ložek 1957, Putiška *et al.* 2017). In the Moravian Karst, the reference site with the best-known lithology and stratigraphy is Kůlna Cave (Valoch 1988). This sequence was also dated by several independent techniques, including biostratigraphy, radiocarbon, ESR and paleomagnetic approach (Valoch 1988; Rink *et al.* 1996; Sroubek *et al.* 2001; Neruda and Nerudová 2014; Nerudová and Neruda 2014). The correlation between the Biśnik Cave and Kůlna Cave sequences was already proposed before (Krajcarz *et al.* 2014). The near-entrance zone of Kůlna Cave hosts an over 10 m-thick sequence that contains, among others, loess deposits. Below the LGM series there are several loess or loess-like strata in superposition: stratified silty loam with debris of Layer 7a (MIS 3); loess of Layers 7c–7d (MIS 4); silty loam with debris of Layers 11a–11b–11c (colder oscillation during MIS 5e); and fluvial silt of Layer 13b (early Eemian, MIS 5e). These units can be easily correlated with the main pre-LGM *cave loess* units in the Polish Jura.

CONCLUSIONS

In contrast to the LGM series of loess deposits in caves and rock shelters of the Polish Jura, the pre-LGM cases are outnumbered. The inner sedimentological and stratigraphic complexity of the pre-LGM *cave loess* series is usually poor. In most of the Middle Pleistocene examples it is limited to thin intercalations dispersed within other lithologies. The presence of a few exceptions, such as the complex packets known from Nietoperzowa Cave and Ogrójec, indicates that this poor record is rather an effect of preservation state and loess susceptibility for erosion, rather than restricted depositional processes.

Poor preservation precludes any reliable reconstruction of the regional variability of pre-LGM *cave loess* in the Polish Jura. However, several observations make these sediments important from a lithostratigraphic point of view. These include: i) the presence of loess deposits in most of the long sequences, below the LGM series; ii) repeating occurrence of loess strata in the same chronostratigraphic positions at several sites; iii) good correlation with loess horizons of the loess-paleosol sequences; and, as a consequence, iv) good correlation of the *cave loess* with the main loess accumulation periods of the Middle Pleistocene and early part of the Late Pleistocene, and also with the arid and cold climatic phases (the same is also valid for the LGM *cave loess*). All these characteristics allow the regarding of the pre-LGM *cave loess* units in the Polish Jura as key paleoclimate indicators, as well as climatostratigraphic units and – if supported with absolute chronology or a well-constrained stratigraphic position – as lithostratigraphic markers. In the light of the accelerating number of excavations in caves and rock shelters of the Polish Jura in recent years (e.g., Sudoł *et al.* 2013; Wojenka *et al.* 2016, 2017; Kot *et al.*, 2019, 2021, 2022a,b; Wilczyński *et al.* 2020; Krajcarz *et al.* 2020; Berto *et al.* 2021), the characterization of the stratigraphic usefulness of loess deposits is of crucial importance.

In this review, only the macroscopic characteristics of sediments were respected. The microscopic features, as well as textural and geochemical data, are available only for few examples of the pre-LGM *cave loess*. Such data, however, together with advanced techniques such as sedimentary DNA, isotopic paleoecology and micro-resolution dating, may provide much more information about the deposition and post-depositional history of loess in caves and rock shelters. It is therefore necessary to implement such studies.

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