Geoarchaeology of Croatian caves

Katarina Gerometta, Giovanni Boschian

This paper discusses the key physical characteristics, formation processes, and postdepositional modifications of several sediment types commonly encountered during excavations in caves of archaeological interest in Croatia, from the Adriatic coast to the hinterland. The geoarchaeological study of these sediments was conducted through field observations, sedimentological analyses, and micromorphological examination of thin sections from undisturbed soil and sediment samples. Although their properties vary considerably depending on the specific site conditions and the environmental context of the surrounding areas, these sediments share a common origin. As such, they offer valuable insights into climatic changes during the later phases of the Late Upper Pleistocene and the Early and Middle Holocene, as well as, most interestingly into human activities within the caves, reflecting adaptations to shifting environmental conditions.

Key words: geoarchaeology, caves, Late Upper Pleistocene, Holocene, Croatia

Introduction

The goal of this work is to outline the characteristics of the most common lithological units (*sensu* NASC, 2005) that occur within the sedimentary records of the archaeological caves situated along the Croatian side of the Adriatic Sea (Fig. 1), following a sedimentological and soil micromorphological approach. The final objectives are to assess the influence of environmental change on the adaptive strategies of human groups that lived in the area and, for more recent periods, to evaluate human impact on the environment. To achieve this, the available geoarchaeological data on the archaeological caves of the eastern Adriatic were reviewed, or were inferred from the descriptions available in literature. No sequences testifying periods earlier than the Upper Pleistocene are currently available, whereas most of the available data refer to sites dated from the Last Glacial Maximum onwards (Karavanić *et al.*, 2014; Ruiz-Redondo *et al.*, 2022).

During the Late Pleistocene (from ~129,000 to ~11,650 BP) (Walker *et al.*, 2018; Head *et al.*, 2021), the climate of Europe was characterised by an interglacial-glacial cycle characterised by several secondary oscillations towards warmer or colder conditions (Blockley *et al.*, 2012; Rasmussen *et al.*, 2014; Seierstad *et al.*, 2014; Mcguire *et al.*, 2024). These phases are very well recorded in the oceanic sediments, whose diachronic variation of oxygen geochemistry is currently divided in stages and substages that are used as fundamental guidelines in the stratigraphy of climate events. From a processual point of view, widely adopted in geological and consequently geoarchaeological studies, the environment (landscape, climate, flora, fauna, etc.) can be subdivided in sedimentary environments, where depositional processes strictly depend on the characteristics of the environment itself. Consequently, the deductive study of the ancient sediments, based on the principle of uniformitarianism, can be used to infer the characteristics of the ancient environments. Observing the sediments accumulated inside caves gives invaluable insights into the environmental change of the past and into human adaptations to the changing conditions of their territories (Farrand, 2001; Karkanas and Goldberg, 2023; Hill, 2024; Nimzing, 2024).

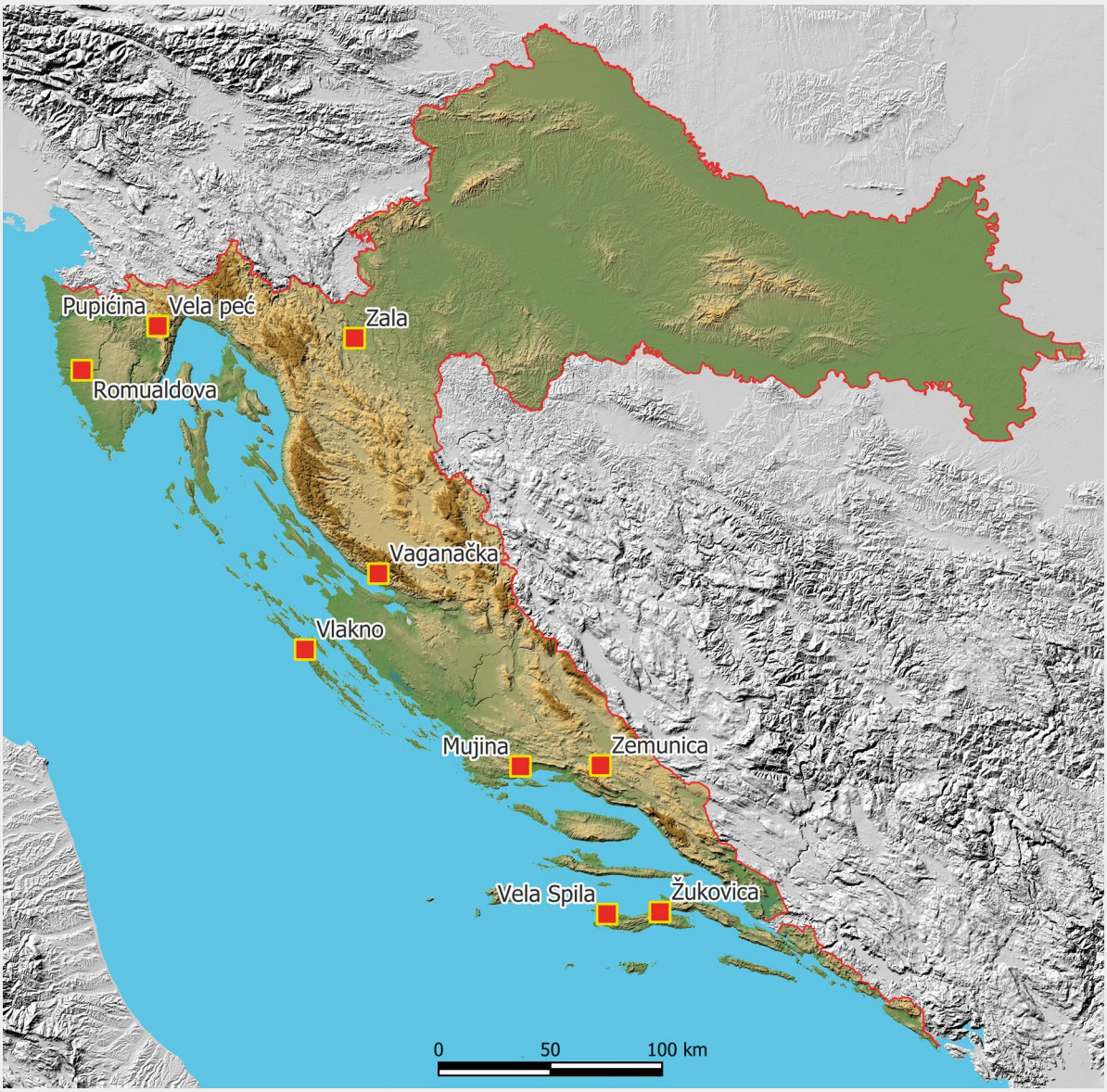


Figure 1. Location map of the caves discussed in the text.

Cold phase sediments

The cold stages are consistently marked by the deposition of limestone clasts. The longer and colder, but also relatively wet, phases are marked by the accumulation of variable size blocks (Fig. 2) whose dimensions depend on the intensity and duration of the cold period, which controls the depth to which water can freeze and act as a wedge within the rock mass. Shorter frost cycles result in thick layers of gravel-size plaquettes, which are probably the most evident feature in Pleistocene cave deposits. Such deposits are typical of cold but relatively aridic phases, when the environmental water is few and cannot penetrate deep into the rock mass. The result is frost shattering due to thermal deformation and spalling of the cave walls and ceiling surfaces (Laville *et al.*, 1980; Lautridou and Ozouf, 1982).

Frost shattering is especially well represented at Mujina Pećina (Boschian *et al.*, 2017), where a long sequence of layers of platy gravel dating to approximately 40,000 BP (isotopic stage 3) marks the end of the Mousterian frequentation (Fig. 3). Similar sediments mark the phase preceding the first human use of Vela Spila (Korčula), likely corresponding to the Last Glacial Maximum (isotopic stage 2) (Čečuk and Radić, 2005; Cristiani *et al.*, 2014; Dean *et al.*, 2020a). Sediments of blocks and plaquettes can often be found in sequence, testifying to the shift from cold and relatively wet full glacial conditions to more aridic but still cold late glacial moments.

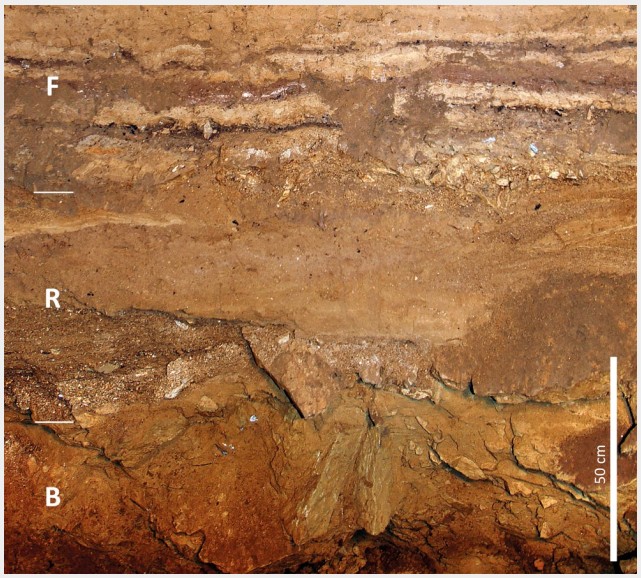


Figure 2. Pećina Zala, near Ogulin. Accumulation of large blocks (B) deriving from ceiling collapse under glacial conditions. The blocks are overlain by underground river sediments R followed by fumier layers (F).

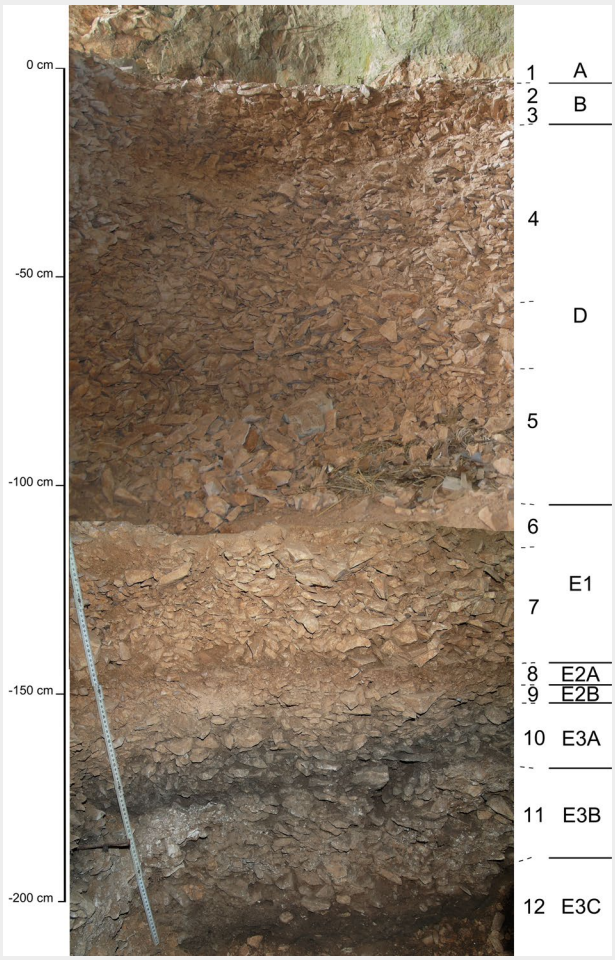


Figure 3. Mujina plaquettes. Mujina Pećina, near Kaštela. The whole sequence of sediments is composed of limestone plaquettes deriving from frost shattering of the cave walls and ceiling. The dark colour of layers E3C and E3A is due to large amounts of amorphous organic matter due to human activities (Boschian *et al.*, 2017).

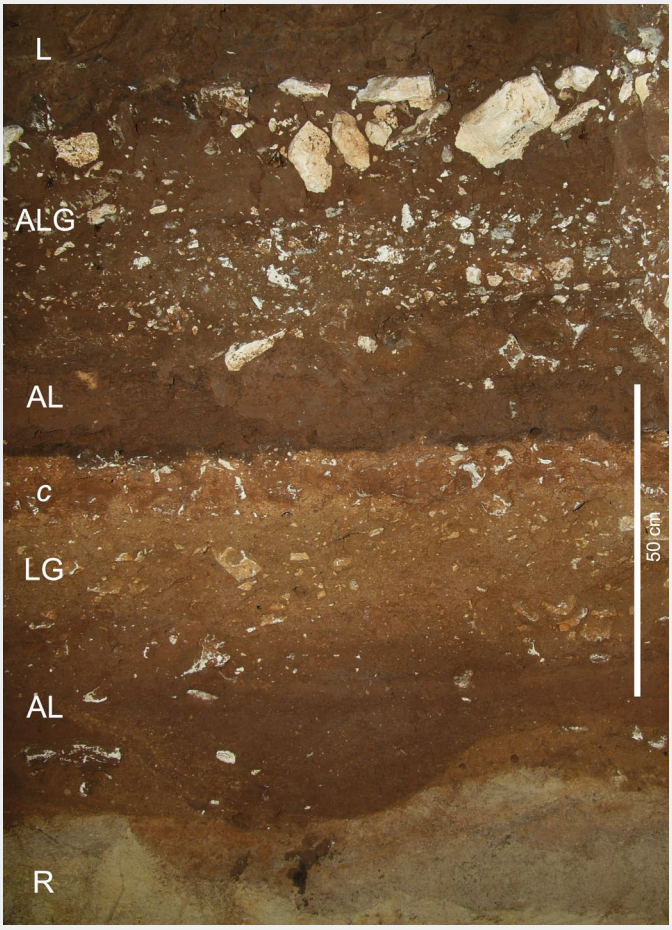
Cold and dry phase sediments

Aridic and cold late glacial conditions also foster the deposition of loess, which is a fine aeolian dust (silt-size, between 20 and 60 μm), often yellowish and moderately carbonatic, whose best examples can be observed on the island of Susak -though not in caves (Pavlaković *et al.*, 2011). This sediment is eroded by wind from the landscape left barren by the glaciers during their retreat, when the still harsh conditions hinder the growth of new vegetation. These areas are in some cases several hundred kilometres far from the deposition area, so that loess is characterised by allochthonous minerals easily transported by wind, like mica flakes, which give the sediment a characteristic glittery aspect. Muscovite is the most common wind-blown mineral and, together with amphibole and augite may indicate a loess source from the Alpine region.

These depositional processes suggest that caves, which are sheltered environments, are not the most likely place where loess would accumulate. In fact, this aeolian dust is mainly deposited on the landscape around the caves, but is soon and easily eroded and transported into them by rain, however rare it may be during aridic phases. Loess sediments in caves are consequently often secondary, or possibly sub-primary, because the dusty and unconsolidated nature of this sediment favours reworking and redeposition.

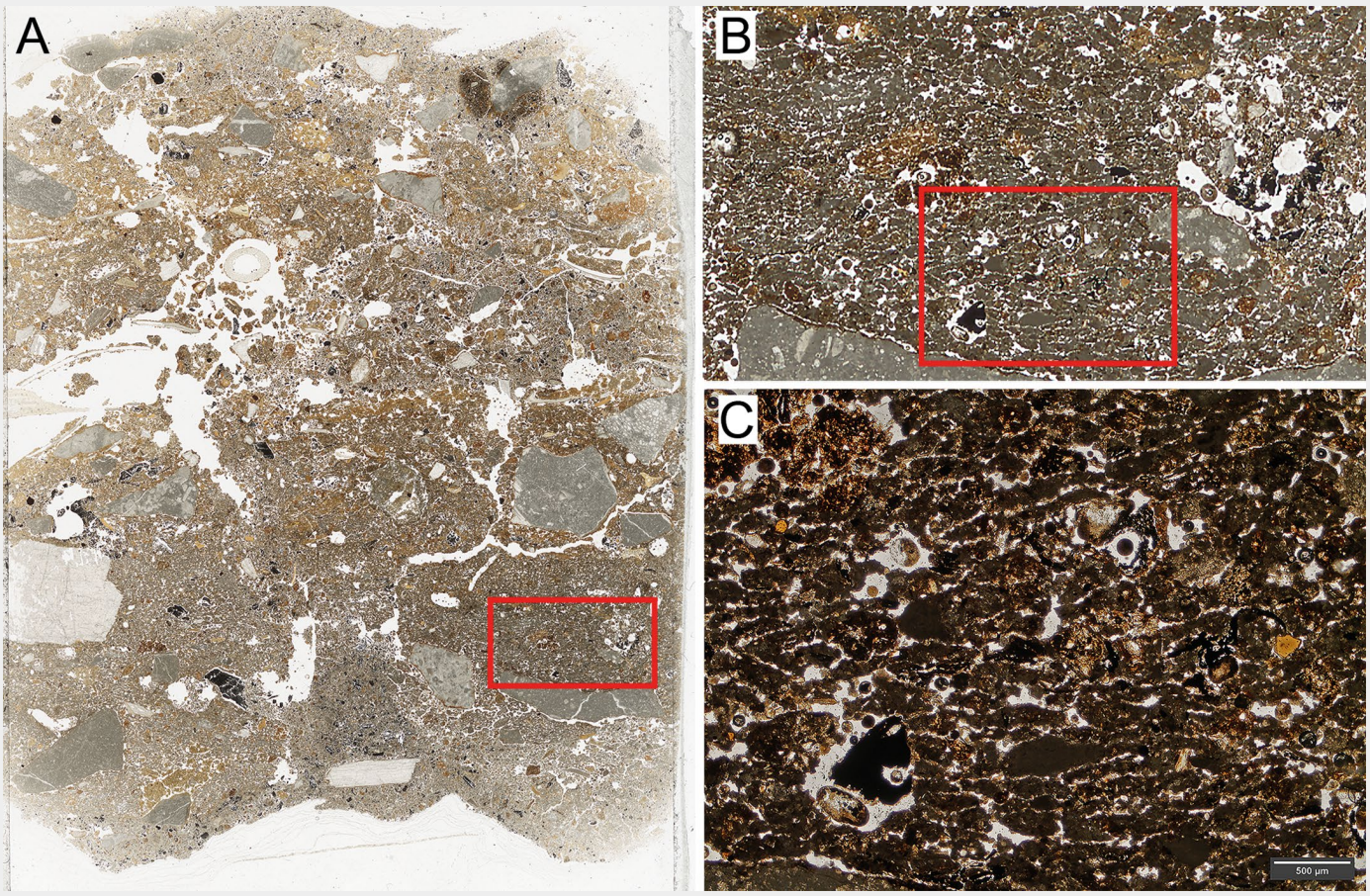
Primary loess can seldom be observed in Croatian caves along the Adriatic coast. Yellowish sub-primary loess mixed with frost slabs was observed at Vela Spilja (Lošinj), whereas the older one corresponding e.g. to the Mousterian layers of Mujina Pećina and Romualdova Pećina (Gerometta, 2017) is brown and somewhat more altered by soil forming processes (Fig. 4), suggesting longer permanence in the outer landscape.

Cold phases can be inferred also from post-depositional features left on pre-existing sediments, recently deposited or much older. Ice wedges, convolutions of the limits between layers (Fig. 5), verticalised stones (Fig. 4), ice lensing (Fig. 6), etc., are all processes linked to the freezing and thawing of the water which impregnates the sediments. Traces of these processes can be observed also at microscopic scale, in thin sections of undisturbed sediment samples.



▲ **Figure 5.** Pećina Zala, near Ogulin. Post-depositional deformation of silty sand sediments sandwiched between limestone rubble layers, forming an ice wedge (W) and flame-like injection features (F), respectively into the underlying and overlying layer.

◀ **Figure 4.** Romualdova Pećina, near Kanfanar. Large part of the sequence is composed of more or less altered loess (AL), often associated with limestone rubble (ALG) deriving from moderate ceiling breakdown. The yellowish LG layer is composed of sub-primary loess associated with gelifraction rubble. Some verticalised clasts resulting from post-depositional frost-heaving can be observed in layer ALG. The sequence rests on river sands (R). Layer *c* was deformed by *boudinage*, a post-depositional frost effect, which transformed the layer into a discontinuous set of irregular aggregates.



▲ **Figure 6.** Vlakno Cave, at Dugi Otok. Post-depositional lenticular structure due to segregation of ice lenses due to deep seasonal frost. A: scan of thin section of undisturbed sediment sample (about 60 mm wide); B: Enlargement of the scan, showing lenticular structure of sediment aggregates (grey) and laminar voids (white); C: microphotographs of the area inside the red rectangle in B, highlighting the lenticular microstructure.

Warm phases

No or very few clastic sediments correspond to the interglacial warm phases within cave sequences, unless the anthropic activity modifies the landscape. The sheltering effect of the forest canopy protects the underlying soils and sediment from erosion and consequent transport into the caves, so that inputs from the outside are extremely limited or absent during these periods. In such cases, only chemical deposition, i.e. formation of speleothems, is active in caves, if the environmental conditions of their interior are favourable.

However, the development of the vegetal cover with its organic inputs, action of root respiration and soil fauna activity favours pedogenetic processes and the consequent development of soil on the landscape around the caves. Soil forming processes are complex and depend on multiple factors: besides time, the nature of the parent material, the climate (temperature, water regime, etc.) play different roles in the development of different soil types. Within this context, primary minerals are transformed by chemical processes into the so-called neoformation minerals (clay minerals, iron and manganese oxides, etc.) (Jenny, 1994; Bockheim *et al.*, 2014).

Traces of soils formed during warm (sub-)stages can be commonly found in cave sediments corresponding to the end of interglacial and onset of glacial phases. The forest canopy shrinks in these periods due to climate deterioration, leaving the soil barren and subject to erosion under the heavy seasonal rainstorms that are typical of these climate conditions (Butzer, 2005). Processes like colluvium, sheet-flow and overland flow transport the eroded material downhill and into the caves, forming layers of reddish clay (Fig. 7), rich in iron oxides and other minerals inherited from the soils. Some micromorphological features corroborate this hypothesis; small reddish, rounded pedorelicts (aggregates strictly resembling soil material, up to 1 cm wide), often bearing rolling traces, were probably eroded from external soils developing on loess and washed into the caves.

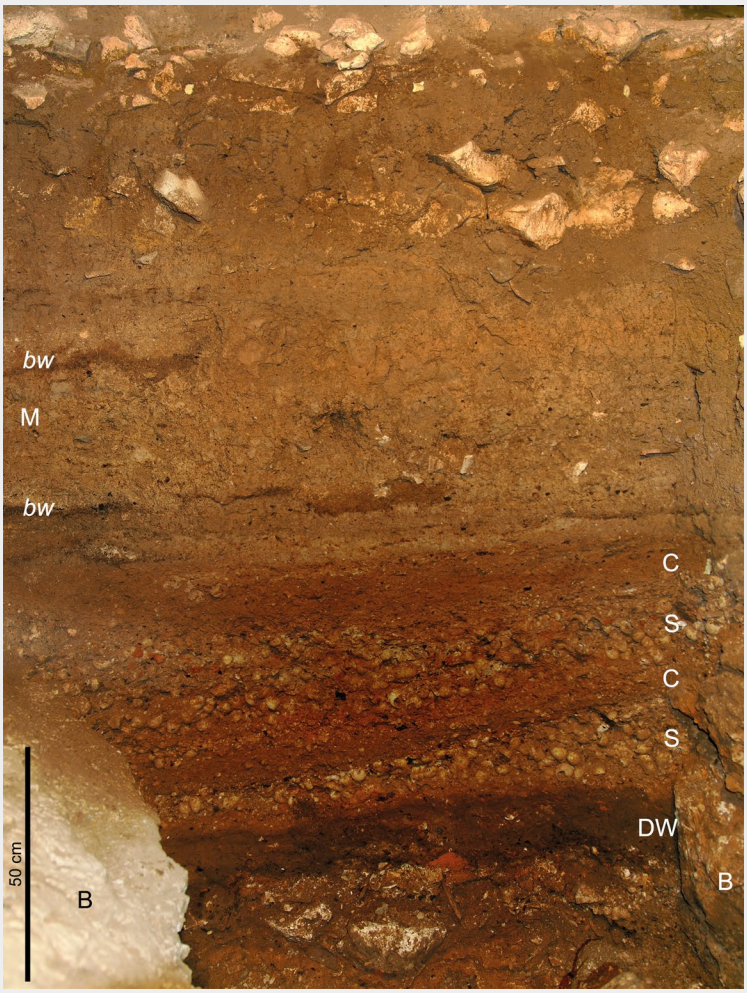


Figure 7. Zemunica, near Bisko. Dark brown Late Upper Palaeolithic domestic waste (DW), rich in amorphous organic matter, overlain by a sequence of reddish colluvia (C) alternating with snail shells (S) including Mesolithic cultural remains. This sequence is embedded in a gap among large limestone blocks (B). The overlying layers include remains of Neolithic to Bronze Age pastoral use of the cave,represented by typical *migon* (M) deposits including the characteristic black and white lenses (*bw*).

The most typical sediment of this type can be found in the Late Upper Palaeolithic levels of Zemunica (Šošić Klindžić *et al.*, 2015; Gerometta, 2017), where they were reworked once more during the Mesolithic frequentation of the cave, and also at Vela Spila (Korčula) in layers including Early Mesolithic cultural remains (Dean *et al.*, 2020a).

Early Holocene (Pre-Boreal and Boreal) deposits share the same sedimentary characteristics as those from the late Late Glacial, i.e. they resemble colluvia of reddish clay and more or less altered loess, although the intensity of these processes appears to decrease. A striking feature is the cultural component superimposed to the natural ones: stone tools, bones, shells, charcoal, wood ash and abundant fragments of decaying organic matter are widespread throughout the sediment, suggesting domestic activities. These characteristics are even more evident at microscopic scale, where large quantities of amorphous organic matter and ash can be in some cases dominant within the sediment. This likely reflects prolonged and repeated occupation of the caves by Mesolithic hunters-fishers-gatherers.

This aspect is widespread in almost all caves observed so far, with best examples from Vela Spila (Korčula), Vlakno Cave (Dugi Otok) and Zemunica.

Human activity

Deposits from the Atlantic period are dominated by human activity, which emerges as the primary factor in sediment formation. Colluvial input is reduced, suggesting re-afforestation and decreased erosion, although this hypothesis should be confirmed by pollen studies. The external inputs increase at the end of the Atlantic and during the Sub-Atlantic because of the deforestation consequent to human activity (such as more intensive agriculture, pastoralism and metal processing).

Two main types of deposits can be distinguished in the horizons from the early Neolithic onwards (Gerometta and Boschian, 2022). The first type is composed of greyish to yellowish homogeneous silty layers, sometimes including isolated thin, extensive black-and-white lenses of charcoal and ash. These layers are sometimes called *migon* by the French Authors (Brochier, 2002) (Fig. 7). The homogeneous silt is composed of variable amounts of randomly dispersed amorphous silica phytoliths, calcareous spherulites (Canti, 1998, 1997) and ash (Canti, 2003; Canti and Brochier, 2017), produced by direct mineralisation of sheep/goat -and later also of cattle- droppings (Brochier, 2002, 1991). The second type of deposits, called *fumier* (again following the French terminology), is characterised by black, white, and brownish silty layers and lenses (Fig. 8), usually resulting in complex sequences that are difficult to excavate because of the irregular shape of the units and of their complex stratigraphy. These units include the same components of the first type of deposits, i.e. charcoal, ash, opal phytoliths, calcareous spherulites, ash and partially preserved burned sheep/goat/cattle droppings. However, unlike the first type, these components are organised in black/white sequences with the black layer representing the base of the doublets, which can be repeated for several metres. This complexity is reflected also at microscopic scale, where distinct beds of pure phytoliths, or phytoliths with spherulites, or pure spherulites, or more or less preserved droppings can be commonly observed. These sediments were produced by intentional and cyclical burning of sheep/goat (and later also of cattle) droppings (Brochier, 1996; Brochier *et al.*, 1992). All these aspects suggest that the caves were used for livestock stabling from the Neolithic onwards, within a complex system of agropastoral exploitation of the landscape.

The most typical deposits of the first type can be found at Zemunica (Šošić Klindžić *et al.*, 2015) and Vela Spila (Korčula) (Dean *et al.*, 2020a; 2020b), whereas the second type is best represented at Vaganačka (Forenbaher and Vranjican, 1985), Pupićina Peć (Boschian, 2006), Vela Spila (Vranska Draga) (Gerometta and Boschian, 2022), Vela Spilja (Lošinj).

▲ **Figure 8.** Vela Peć, inside Vela Draga on Učka mountain. Typical *fumier* pastoral sediments, with alternating black-white-grey layers/lenses composed of charcoal, ash, phytoliths and spherulites.

Conclusions

The geoarchaeological study of cave sequences along the eastern Adriatic coast provides a reliable reconstruction of environmental dynamics and human interactions with the landscape from the Upper Pleistocene through the Holocene. Cold stages are primarily represented by clastic deposits (including frost-shattered plaquettes and blocks) reflecting periglacial processes associated with varying degrees of aridity and temperature. Loess inputs, usually preserved as sub-primary contexts within caves, testify to an aridic and windswept Late Glacial landscape, with redeposition mechanisms that suggest periodical intense rainstorms. Interglacial and interstadial warm phases are typically marked by a marked reduction in clastic input due to stabilisation of the landscape under dense vegetation cover. Here, pedogenetic processes contribute to the formation of clay-rich soils, which are subsequently deposited as colluvia within the caves during transitional climatic phases. These sediments serve as important proxies for landscape degradation events linked to climate deterioration and erosion. From the Early Holocene onwards, the sedimentary record increasingly reflects human activity. Domestic residues such as charcoal, ash, and organic matter become widespread in Mesolithic layers, indicating repeated and prolonged cave occupation. In Neolithic and later contexts, the sedimentary signature is dominated by livestock stabling practices. This is evidenced by the presence of ash, phytoliths, spherulites, and dung residues, structured in complex, cyclic stratigraphies indicative of repeated burning episodes. The cave sequences of the Croatian Adriatic thus offer valuable insights into long-term environmental fluctuations and their influence on human occupation strategies. Furthermore, from the Neolithic onwards, they reveal the progressive emergence of humans as a dominant geomorphological and sediment-forming agent, reflecting broader patterns of land use and socio-economic transformation in the Holocene.

It can be concluded that cave sediments -and more generally the sediments of archaeological sites- represent records of environmental change and of human activities that were influenced by the shifting environment. There is consequently a strict link between these sediments, their characteristics and formation processes, and human culture. Archaeological studies cannot disregard the in-depth geoarchaeological study of sedimentary sequences, which must be considered as cultural remains.

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Geoarheologija hrvatskih špilja

Ovaj rad razmatra ključne fizičke značajke, formacijske procese te postdepozicijske preinake nekoliko tipova sedimenata koji se najčešće susreću tijekom iskopavanja u špiljama od arheološkog značaja u Hrvatskoj, od jadranske obale do zaleđa. Geoarheološko proučavanje ovih sedimenata provedeno je terenskim opažanjima, sedimentološkim analizama i mikromorfološkim ispitivanjem izbrusaka uzoraka netaknutog tla i sedimenata. Iako se njihova svojstva znatno razlikuju ovisno o specifičnim uvjetima nalazišta i okolišnom kontekstu okolnih područja, ti sedimenti imaju zajedničko porijeklo. Kao takvi, pružaju dragocjene uvide u klimatske promjene tijekom kasnijih faza gornjeg pleistocena te ranog i srednjeg holocena, ali, što je osobito značajno, i u ljudske aktivnosti unutar špilja odražavajući prilagodbe promjenjivim okolišnim uvjetima.

Ključne riječi: geoarheologija, špilje, kasni gornji pleistocen, holocen, Hrvatska

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