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Hydrogeological conceptual model of loess deposits: a case study from eastern Croatia

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ABSTRACT
Loess is a predominantly silt-sized continental aeolian sediment covering 10% of the Earth's land surface. Groundwater generally represents the most important source of potable water in loess areas, where loess is the aquitard overlying aquifers. Despite its importance in aquifer protection, its hydrogeological properties are partially investigated. This work reviews the well-established depositional and post-depositional processes affecting this deposit to elucidate its hydrogeological behaviour. The result is beneficial to propose a hydrogeological conceptual model of aquitard-aquifer systems in loess areas.

Keywords: loess, conceptual modelling, eastern Croatia

METHODS
Pleistocene loess deposits crop out in eastern Croatia where they represent the layer separating aquifers, exploited for water supply and agricultural purposes, from the surface. Tectonic uplifting and river erosion expose loess in several representative sections investigated using sedimentological, mineralogical, geochemical and geochronological approaches (e.g., Galović, 2016; Wacha et al., 2013). Conversely, the hydrogeological setting of these deposits is not established. Similarly, the underlying sandy aquifers were investigated by local studies, but their results have never been put in a regional context. First, available sedimentological data extended by new investigations and complemented by literature reviews (e.g., Barta, 2011; Smalley et al., 2016) were used to evaluate the impact of the depositional and post-depositional processes on the hydrogeological behaviour of loess. Afterwards, three regional scale areas in eastern Croatia were selected (Fig. 1a). The available geological and hydrogeological data were collected to reconstruct their hydrogeological settings.

RESULTS
Loess in the representative sections contains 80-90% silt-sized particles and small amounts of clay. The original sediments, which were formed by glacial grinding of bedrock in Alpine region, were transported by fluvial systems towards periglacial areas, deposited on alluvial plains and subsequently remobilized by wind. The windblown silts were redeposited either on land or in lakes and wetlands

forming loess or loess-like deposits (Fig. 1a), respectively. During interglacial periods, pedogenesis could occur. Several organisms lived in both the soil and the underlying original deposit producing different types of discontinuities. Vertical or subvertical root channels are common (Fig. 1b) and, if they are not filled by clayey material, they can represent a preferential path for the water flow even through well-developed palaeosoils. The deposition of secondary carbonates and iron minerals (Fig. 1c) at the border of these channels testifies to the occurrence of flowing water corroborating their impact. Loading by newly deposited sediments and concomitant wetting result in the compaction and contraction of the previously deposited loess. Polygonal cracks produced by the hydroconsolidation (Fig. 1d) or fissures related to neotectonic deformation are typical post-depositional features in loess constituing preferential flow paths as well. Furthermore, compaction produces a decrease of the void ratio affecting the porosity of the deposit. Studies about ideal packing suggest that the void ratio usually decreases from 1 to 0.6 in loess. The resulting theoretical total porosity is 37%, a value that approaches the lower limit of loess porosity range reported in literature (42-55%; Li and Quian, 2018). However, calculations based on a few grain size distributions of eastern Croatian loess deposits and their mean referential grain sizes point to a low effective porosity from 5 to 9%.

CONCLUSIONS

These are the first results of a recently started research investigating the hydrogeological characteristics of loess deposits in Croatia. The proposed hydrogeological conceptual model suggests that loess is a partial aquitard characterized by low effective porosity. This points to its generally low permeability. However, several depositional and post-depositional processes can produce mm to cm scale voids increasing its value at the macroscale. The reinterpretation of stratigraphic logs in the three study areas is still ongoing. The obtained results will allow to establish the horizontal and vertical contacts among recent alluvial sediments, loess and water-bearing sandy layers and to reconstruct their hydrogeological settings. The reconstructions will be populated with multi-scale porosity and permeability measurements of loess and sandy layers investigating the scale dependency of these properties to achieve a representative multiscale hydrogeological conceptual model of loess-sand aquitard-aquifer systems.

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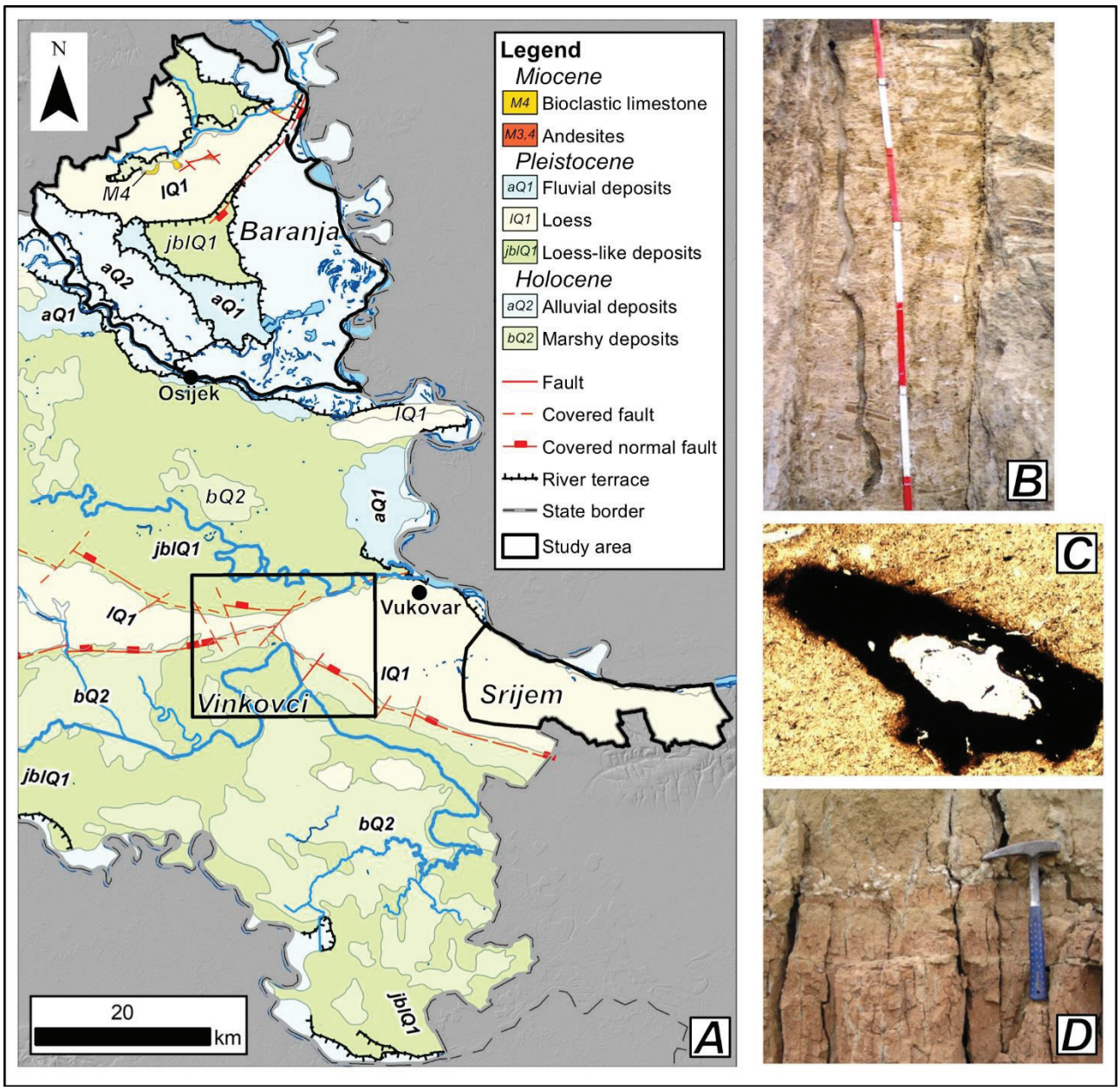

Fig. 1 - (A) Geological map of eastern Croatia. (B) Root channel in loess-paleosol sequence. (C) Hypocoating deposited in a root channel. (D) Vertical cracks due to hydroconsolidation of loess.