Analysis of The Loess Geological Environment in Terms of Engineering-Geological and Geotechnical Purposes and Application in Geotourism

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Abstract. Loess sediments, formed via wind action, are important geological environments both for the engineering geology as well as for the newly developing field in the geosciences, i.e. geotourism. The paper aims to give the basic characteristics of loess sediments and point at two localities in the Czech Republic, where significant archaeological localities are situated on loess. The first locality is Mikulčice in the Hodonín district in the South-Moravian Region. The second locality is Chtěbuz in the Karviná district in the Moravian-Silesian Region. The two localities are important examples for tourists and scientists searching for the sights related to their geological environment. Loess sediments have specific characteristics that arise from their genesis.

1. Introduction
Currently, the modern trend in engineering geology is to individually perceive the different geological environments. Such an approach permits a suitable application of the knowledge and properties of the environments in analogous environments of other localities. One of the environments are loess sediments formed via wind action. Loess sediments are represented world-wide and in the Czech Republic there are also localities with loess. The paper aims to describe this geological environment along with its properties and characteristics as such information may be used in various interactions during construction works. The information may also be equally useful for the agriculture, forestry and land-use planning. The second aim is to emphasize their geotourism potential and give two localities in the Czech Republic as examples of interesting and specific environments.

2. Characteristics
Loess is a detrital sedimentary rock covering 5-10% of all continent surfaces. It is dominant in the steppes with intense air currents. Loess formed mainly in the cold periods of the Pleistocene to Holocene under periglacial conditions. As for foundation engineering, it is mostly the case of medium-bearing soils of stiff to solid consistency and low to medium plasticity. According to ČSN 73 1001 Standard it...
falls in the category F6 – clays of a low plasticity (Cl), and according to ČSN 73 3050 Standard, in
dependence on plasticity it is classified into rock workability class 2 - 4. Among other properties there
is possible differential settlement, more prominent vertical permeability and porosity. Loess is made up
by silt grains of ~ 0.05 mm. These get into the atmosphere by means of strong rising gusts and silt clouds
form. The clouds may be transported by wind for thousands of kilometres. By means of descending
airflows, the silt grains get back onto the surface in the form of dry deposits. Another option is
sedimentation of silt grains from rainfall [1]. Grains of bigger fractions (coarse sand) are transported by
traction along the ground, and medium to fine sand is transported by saltation [1]. This transport is
characteristic of the surface finish of the different grains. The silt sources may be deserts and bare
deflation areas in places, where glacial, fluvial, alluvial or proluvial sediments freshly deposited. Loess
is highly valuable for agriculture and is a suitable raw material for brick production. [2, 3, 4]

3. Loess composition and structure
Loess contains mainly quartz and to a smaller extent, there are the grains of carbonates, feldspar and
mica. Clay minerals are important components, along with approximately 40% of CaCO₃. The loess
character depends on the source rocks. The calcium content in loess does not depend on the geological
base. Carbonates liberate from silicates by means of silicic-carbonate weathering and the action of
microorganisms. As for the loess structure, it is characteristic of a high porosity (n > 40 %) and basaltic
jointing without prominent lamination (see Figure 1). [2, 3, 4, 5]

There are macroscopic pores that close up when wet and softened. Typical for loess is the
permeability by vertical fissures, along which they dissolve under water presence. When dry, loess is
typical for a considerable strength, but when wet it loses the strength and begins to compress. The
vertical permeability is 40x higher than the horizontal one. Thanks to the above stated properties, loess is
considered a highly compressible soil. However, more often than loess we come across loess loam,
whose pores are filled with clay particles. If the specific gravity γₛ does not reach 1.3 t/m³, measures
must be taken, e.g. piles into deeper bedrock (see Chyba! Nenašiel sa žiaden zdroj odkazov.). Loess
loam may be rather well stabilised chemically by lime or cement. Due to this, settlement or differential
settlement may be reduced significantly. The foundation surface must be protected against waterlogging
[6].

| γₛ (t/m³) | Foundation engineering |
|-----------|------------------------|
| < 1.3     | Highly hazardous        |
| 1.3 – 1.5 | Hazardous              |
| 1.5 – 1.6 | Relatively safe         |

4. Mechanical properties of loess
The mechanical behaviour of loess (strength versus deformation) is determined based on the content of
carbonates and clay particles. Loess with a higher carbonate content to clay particle content has a higher
strength. This holds true until the moment of structure disturbance, when deformation occurs and loess
break-down follows. On the other hand, loess with a higher content of clay particles has a lower initial
strength, but if its structure is disrupted, its break-down is not that fast as in loess with a higher carbonate
content. In this respect, loess with a high content of clay is the best as it does not lose its shape under
strain and it behaves as elastic-plastic fine-grained cohesive soils, [7, 8].

If we look at the susceptibility of loess to collapse, the coefficient of loess collapsibility Iₘₚ is used as
the basic characteristic for the calculation of structure settlement or of the general characteristic of
soil ability of subsidence. It is the ratio of soil specimen settlement at a given strain and following
waterlogging to the specimen height before saturation (difference between before and after saturation).
Soils may be considered as prone to subsidence when the collapsibility coefficient $I_{mp} > 1\%$ at vertical stress corresponding to the overburden load, including excess load due to, for example, engineering construction. [9]

Formula to calculate the coefficient of collapsibility:

$$I_{mp} = \frac{\Delta h_p}{h_0} \times 100\%$$

- $\Delta h_p$ - vertical deformation of a specimen when waterlogged at a given strain in mm.
- $h_0 = h - \Delta h$ - difference between the original specimen height of naturally wet soil $h$ in mm and vertical deformation $\Delta h$ from the start of the test to complete saturation. [7]

Table 2 gives an evaluation of the soil susceptibility to collapse based on the collapse index [10], as well as the Guideline of the Ministry of the Environment of the Slovak Republic (MŽP SR) to set up the geological factors of the living environment [11].

Table 2. Soil susceptibility to subsidence according to Lin and Wang, and the Guideline of MŽP SR [10, 11, 12]

| Soil susceptibility to subsidence                        | Collapse index (%) Lin and Wang (1988) | Collapse index (%) Guideline of MŽP SR (1996) |
|----------------------------------------------------------|----------------------------------------|-----------------------------------------------|
| Non-collapsible                                          | 0 – 1                                  | < 1                                           |
| Medium / slightly collapsible                            | 1 – 5                                  | 1 – 1.5                                        |
| Very collapsible                                         | 5 – 10                                 | 1.5 – 3                                        |
| Very highly / highly collapsible                         | 10 – 20                                | > 3                                           |
| Extremely collapsible                                    | > 20                                   | –                                             |

Table 3 gives the soil susceptibility to subsidence based on porosity [13], while Gibbs and Bara (1962) in their publication 'Predicting surface subsidence from basic soil test' determine the degree of
subsidence based on the relation of dry soil bulk density and the liquid limit [14]. They suppose that soils may be considered as non-collapsible if the soil reaches equal or higher moisture than the water content on the liquid limit is [7].

Table 3. Dependence of loess degree of collapse on porosity according to Maslov and Kotov and Regulation of MŽP SR [13, 11]

| Soil susceptibility to subsidence | Porosity in % Kotov, Maslov | Porosity in % MŽP, SR | Collapse of loess (mm·m⁻¹) Kotov, Maslov | Collapse of loess (mm·m⁻¹) MŽP, SR |
|----------------------------------|----------------------------|------------------------|--------------------------------------------|----------------------------------|
| Non-collapsible                 | < 40                       | < 40                   | 0                                          | < 10                             |
| Slightly collapsible            | 40 – 45                    | 40 – 46                | 10                                         | 10 – 15                          |
| Collapsible                     | 46 – 50                    | 46 – 52                | 50                                         | 15 – 30                          |
| Highly collapsible              | 51 – 55                    | > 52                   | 100                                        | > 30                             |
| Very highly collapsible         | > 50                       | –                      | > 100                                      | –                                |

5. Loess distribution

Loess is abundant mainly in North and South Americas, Europe, Asia and New Zealand. In the central Asia there is loess of the Upper and Medium Pleistocene. Thanks to the longer interglacial conditions, some soil horizons are thicker than the recent soil. In China loess covers an area of 275 600 km², where it reaches the average thickness of 100 m and the maximum thickness is 300 m. It formed under arid glacial conditions for the past 2.5 million years and 37 soil units have formed there. The sources of the silt transported by the north-western wind are the Gobi Desert and Siberia plains. [3]

In the USA loess represents 30% of the overall area, i.e. from the north-western parts of the Rocky Mountains to the Mississippi River Valley. Its thickness does not exceed 60 m. Mostly, it is loess of the last glacial, exceptionally it may be 400 – 500 thousands years old. [3]

Similarly to the USA, Argentina mostly has loess from the last glacial. Its surface area covers 200 000 km². [3]

In Europe loess is characteristic of higher humidity. It stretches as a discontinuous, 150-km-wide belt from the north of France to Ukraine. Its thickness is up to 50 m. [15]

In the Czech Republic the altitude limit for calcareous loess occurrences is 300-400 m a.s.l. In wet localities, e.g. the Ostrava Region, loess also occurs at the altitude of 200 m a.s.l. We distinguish two major sources of silt, namely local and remote. Among local silt sources there is for example cretaceous marl silt and sand (Kladno Region) and silt and sand from the Labe terraces (Hradec Králové). A remote silt source is, for example, glaciofluvial sediments at the foothills of the Alps and the sediments of the continental glaciation in North Moravia. [16]

6. Geotourist significance of loess

From the point of view of geotourism, loess is a very interesting environment. Loess Quaternary sediments are frequent environments where archaeological excavated materials are found, both in the Czech Republic, and abroad. Significant archaeological prehistoric sites are being reconstructed under the national or EU subsidies or museums with archaeological exhibits are opened in such localities. This contributes to a higher cultural and historic value of the localities as well as improved tourism. Among the most significant archaeological sites in the Czech Republic there is for example Slovanské hradisť in Mikulčice. This national cultural monument is found roughly 3 km from the municipality Mikulčice. The Great-Moravia Castle from the 8th and 9th centuries with extensive extramural settlement on the isles within the Morava River on an area of 50 ha belongs to the most extensive Slavic archaeological sites in the Czech Republic. In the local museum we can find various everyday objects, such as ceramics,
stone objects or iron forged pieces as well as artistic products that the local founders and jewellers made from iron, bronze, silver and gold. We may thus admire magnificent accoutrements, such as swords and spurs, and various jewels, for example, ear-rings, buttons and rings. Real rarities are wooden findings that normally do not preserve. An example are wooden boats that were discovered during the former river bed investigations. With regard to the overall size of the site and the discovered objects, this national cultural monument has been nominated for the UNESCO World Heritage Site List. [17, 18]

As for the Ostrava-Karviná Region, an important archaeological site is the Archeopark in Chotěbuz near Český Těšín. This almost reconstructed site of discovery belongs among the most significant prehistoric and medieval monuments in Těšín Silesia. The Archeopark spreads on the site of an ancient Slavic site of an ancient settlement and is a reconstruction of a Slavic settlement from the half of the 8th century to the 11th century. Among the most significant archaeological findings there are, for example, the accoutrements of warriors on horses (spurs, bits), or weapons giving evidence on the violent downfall of the settlement, e.g. arrow-tips, knives and axes. Among many findings there are also many articles of everyday use, such as water buckets, scissors, a scythe, etc. Among curiosities there are well-known iron manacles used in slave trade. Excavations have taken place since the half of the 19th century and so far only about 18% of the overall area have been investigated. In future, excavations should gradually continue to cover the whole premises. [19]

Loess is an interesting environment also for palaeontologists. It is long-term stable and an ideal fossilising environment for molluscs’ calcareous shells and vertebrates’ bones. [20]

7. Conclusions
The environment of loess sediments must be perceived as an important part of the different geological environments. Considering its extensive distribution, loess is economically valuable. As for engineering geology, it is an environment in which we encounter problems with differential settlement in specific cases. This does not concern all types of loess, but only loess containing calcareous grains of higher porosity (n > 40 %) and saturation level. Loess also has a geotourist significance and it provides an environment for a number of notable cultural monuments, including archaeological prehistoric sites. As examples we may state two important Slavic archaeological monuments in Mikulčice and Chotěbuz. The most important finding in loess is the Venus of Věstonice, which was discovered in Lower Věstonice in 1925. It dates back to the 29 000 – 25 000 years before Christ and it is the oldest known ceramic figure in the world (made of loess and crushed burnt bones).

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