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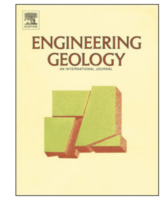


# Determination of erosion thickness by numerical back analysis: The case study of Badenian clays in the Carpathian Foredeep, Czech Republic

Richard Malát [a,*], Josef Rott [a], Monika Černíková [a], Juraj Franců [b], Jan Boháč [a], David Mašín [a]

[a] Faculty of Science, Charles University, Albertov 6, 12800 Prague, Czech Republic
[b] Czech Geological Survey, Leitnerova 22, 65869 Brno, Czech Republic

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A B S T R A C T

The paper describes an application of the geotechnical numerical back analysis in estimating the thickness of eroded sedimentary overburden in shallow basinal sediments. The approach is based on the back-analysis of the coefficient of earth pressure at rest $K_0$ and on estimating the unloading from the obtained $K_0$ value. This approach is compared with the conventional methods represented by Baldwin–Butler's "compaction curves" and Casagrande's concept of "preconsolidation stress". The results of these two commonly used methods are incorrect if the sedimentary profile is affected by "ageing" effects, such as cementation, secondary compression etc. The method is demonstrated on the Lower Miocene marine clay, often called "Tegl" which was deposited in the Carpathian Foredeep in the vicinity of Brno, Czech Republic. The numerical back analysis was applied to galleries and adits opened during site investigation of the Královo Pole Tunnels in Brno. The application of Baldwin–Butler's equation suggested the erosion thickness of 180–270 m and Casagrande's method of 100–800 m, while the numerical back analysis of 0–40 m.



## 1. Introduction

The thickness of erosion of sediments can be estimated using purely geological approach determining the altitudes of the current surface of the stratum and its denudation relics. An essential disadvantage of this approach is the fact that the result can be significantly affected by tectonic (vertical) movements. In order to avoid the problem, several techniques based on analyses of the mechanical properties of the soils have been developed. But it is well known that most mechanical properties of soils change during ageing (e.g., Chandler, 2010; Mesri and Hayat, 1993). The ageing effects are difficult, or impossible to quantify, and invalidate the estimates of the erosion thickness. This also disqualifies the two most common methods based on the analysis of mechanical properties: Baldwin and Butler's equation (1985) and Casagrande's method (1936).

Determining the erosion thickness by the proposed geotechnical numerical back analysis does not have to consider the ageing effects, which would be necessary in both Casagrande's and Baldwin–Butler's method. On the other hand, the procedure assumes that there is no change in horizontal stress due to ageing. The literature review, however, revealed that the effects of ageing on the horizontal stress (and $K_0$) in clay massifs has not been solved to date. Nevertheless assuming constant horizontal stress seems to be plausible (Holz and Jamiolkowski, 1985; Gareau et al., 2006). In the following, the results of a numerical back analysis are compared with Baldwin–Butler's and Casagrande's methods.

A soil affected by ageing had to be chosen for such a study. The Miocene clay of the town of Brno called "Tegl" seemed a good candidate for such an exercise: it had clearly been subjected to ageing since its sedimentation in the Carpathian Foredeep, and its thickness of erosion is still a matter of dispute. The estimated values vary from tens to hundreds of metres (e.g., Boháč and Pavlová, 2012, Pavlík et al., 2004). Moreover, a well-documented geotechnical case-history was available for the study – the Královo Pole Tunnels project, during which exploratory adits, drifts, and final motorway tunnels were excavated in the Tegl strata (Pavlík et al., 2004; Svoboda et al., 2009, 2010).

## 2. Geological setting

The analyses were made on Middle Miocene, Early Badenian calcareous clayey sediment in the Carpathian Foredeep, further referred to Tegl. The Early Badenian (Moravian) sediments of the Carpathian Foredeep basin were deposited during a marine transgression from the ESE on the East margin of the Bohemian Massif. The lowermost units include the Iváň Beds and basal Brno sandstones and conglomerates with local maximum thickness of 190 m (Stráník et al., 2016). They are overlain by deepwater fine grained sediments described as Tegl. This unit without a formal lithostratigraphic name consists of blue-, brown- to green-grey massive calcareous clay with sandy

* Corresponding author.
*E-mail addresses:* malat@natur.cuni.cz (R. Malát), rottj@natur.cuni.cz (J. Rott), cernikom@natur.cuni.cz (M. Černíková), juraj.francu@geology.cz (J. Franců), bohac@natur.cuni.cz (J. Boháč), masin@natur.cuni.cz (D. Mašín).

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laminae and horizons in the lower part. Frequent lenticular bodies are enriched in organic matter and fragments of molluscan shells. Tegl onlaps on the pre-Neogene units in the West and widely surpasses the regional extent of the basal clastics. This transgression is correlated with the eustatic sea level rise of the global ocean and the paleo-water depth is estimated to be as high as 100 m West of Brno city while 200–500 m in upper bathyal setting in Brno-Královo Pole (Brzobohatý, 1982). Radiometric measurements of rhyodacite tuffs and tuffitic clays, which occur in local interlayers, provide age estimation of 16,2 ± 2,1 mil. years (Nehyba, 1997). The maximum known thickness of Tegl is more than 1000 m East of Ostrava city.

Tegl is a Tertiary calcareous silty clay. The clay fraction is composed of illite, montmorillonite and kaolinite, the silt fraction consists mostly of quartz and calcite. Tegl also contains gypsum, pyrite and iron hydroxides, which are products of the pyrite oxidation. Calcium carbonate is present in the crystalline form (calcite). The amorphous form of the calcium carbonate that could cause the cementation is not present, because the calcite precipitation from the solutions during post sedimentation process does not support formation of the amorphous form.

It is obvious that the top of the deepwater Early Badenian is erosional and that younger sediments which covered Tegl have been removed. The strata are influenced by ageing effects, such as secondary compression (Boháč and Pavlová, 2012) or tectonic movements (Pavlík et al., 2004). The thickness of the eroded units has not been estimated in a satisfactory manner up to now.

## 3. Investigated sites

Samples and data from two sites in the area of Brno town were used. Data from Brno - Královo Pole (Královo Pole Tunnel project) were used in the numerical back analysis. After completion of Královo Pole tunnels, however, obtaining of new undisturbed samples of Tegl was impossible in the developed area. The samples for analyses according to Baldwin–Butler's and Casagrande's proposals were therefore taken from Brno - Slatina (position of the V1 borehole in Fig. 1). The thickness of erosion of Tegl for both site is assumed to be the same or very similar due to several reasons:

1) No significant tectonic movement has been identified between the areas.

2) The current surface of the Tegl stratum is approximately at the same level at both sites (ca 230–245 m above sea level).

3) The coastline of the sea during deposing of the stratum is estimated to be 15–30 km from the investigated sites and that is why horizontal surface of Tegl after depositing is assumed for both sites.

### 3.1. V1 borehole

The borehole V1 was situated in Brno town between Drážní and Šmahova streets. Coordinates of the axis of the borehole are: 49.1709261N, 16.6826475E (WGS84). The surrounding is flat and reaches approx. 250 m above sea level. Quaternary sediments are

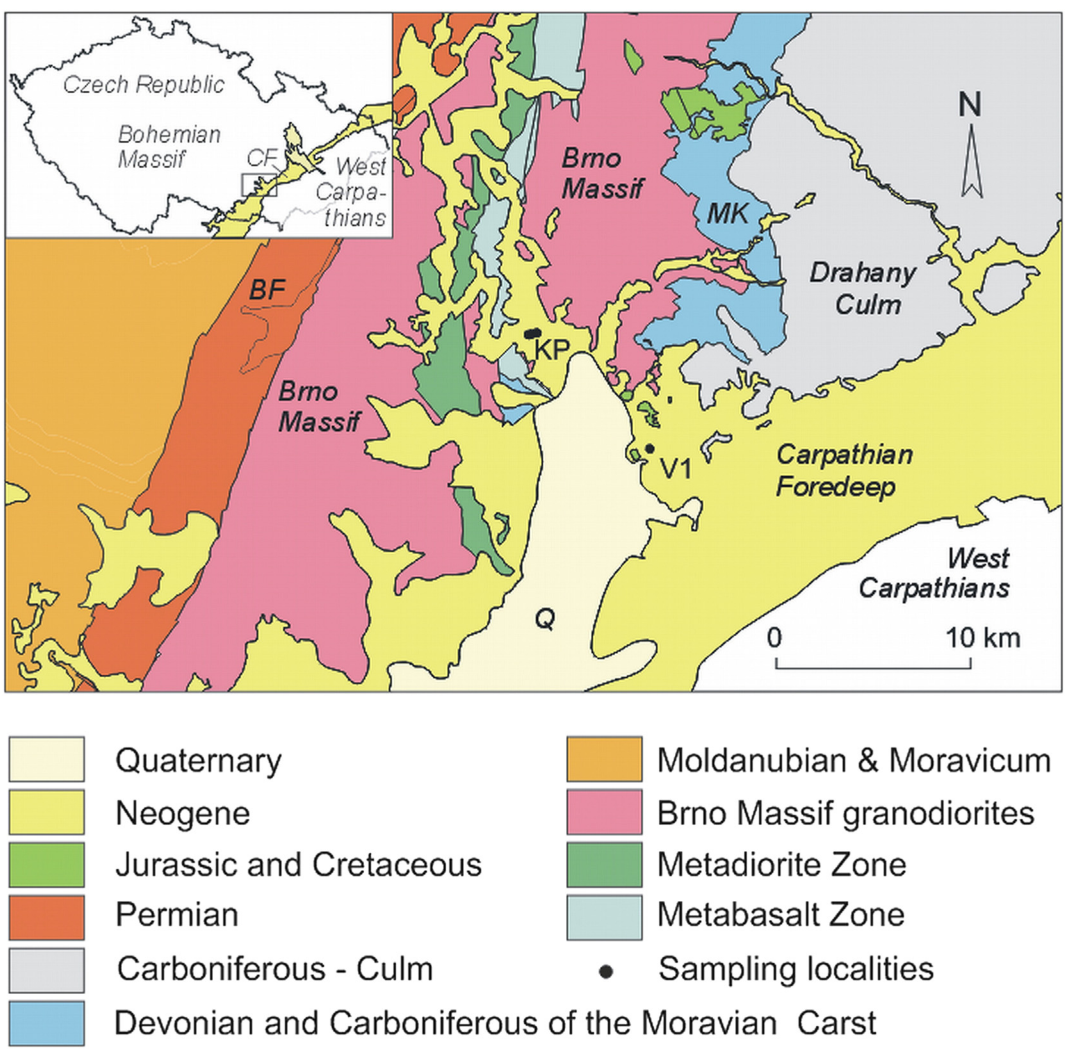


**Fig. 1.** Locations of KP (Královo Pole tunnel) and V1 (Brno Slatina) boreholes. The yellow area shows the extension of the Carpathian Foredeep, adjacent geological units are shown for reference. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)