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# PEDOLOGICAL CHARACTERISTICS AND MINERAL COMPOSITION OF RED CLAYS IN HUNGARY

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## ABSTRACT

Representative samples were selected for the study from a large number of profiles. Mineralogical, some micromorphological and pedological investigations of typical samples of red clays in Hungary were performed. On the basis of soil and mineral analysis these red clays can be ranked in various groups:

- Red clays in Transdanubia: red clays formed on Permian sandstones, bauxitic formations of Transdanubian Hills,
- Red clays of Northern Mountains: red clays of Tokaj Foothills, of Aggtelek Karst, of Northern Periphery of the Hungarian Plain.

Concerning micromorphological features, speckled and granostriated b-fabrics of the groundmass, mainly due to swelling and shrinking, were observed in some samples. Clay coatings are mainly interpreted as micromorphological features of illuviation. Red clays investigated are similar to the tropical and sub-tropical ferrallitic soils in respect of their formation and mineral characteristics.

***Key words:*** red clay, red soil, tropical weathering, lateritization, rubefication, micro- morphological features

## INTRODUCTION

Red clays in Hungary are the products of soil forming processes occurring during the Tertiary period, which were not covered later by marine sediments. They were eroded under the climatic conditions of the Quaternary Period, so today they can only be found in areas where they are protected against degradation, or where due to their thickness and resistance they could withstand the forces of erosion. Thus, red clays are fossil or relict products of soil formation, since both their water regime and nutrient supply differ from soils formed in the Holocene. Their economic importance is far from negligible; vineyards, forests and arable cultivation can be found on these areas. Their influence may be detected in larger area where they are washed away, settled and became mixed with other soils.

## GEOLOGICAL SETTINGS

Varying views on the formation, properties and distribution of red soils in Hungary have been published by numerous authors. Geologists took an early stand on the origin of red clays. The formation of the several red-coloured clays and silts were variously explained, sometimes with contradicting opinions. Lóczy (1887) described red clay as a formation closely related to loess, in respect of age and origin. Treitz (1903, 1912) shared this view, stating that red clays, as a product of soil-forming processes, were formed from wind-blown material in the Quaternary Period. It is the B-horizon of soils beneath forests established on loess, where the A-horizon was eroded.

Timkó and Ballenegger (1916) held similar views about these soils. A peculiar type of red clay is the clay soil (nyirok) formed on volcanic rock in Tokaj-Hegyalja (foothills of the Tokaj Mountains), which was first described by Szabó and Molnár (1866) and characterized in detail by Ballenegger (1917), who reiterated Szabó's ideas. The red clay (nyirok) at Tokaj-Hegyalja is a relict soil from the Tertiary Period formed by the weathering of young, volcanic rocks and their tuffs under subtropical climatic conditions. Generally the term „nyirok", in a wider sense is often applied for the red clays.

The contemporary knowledge of the conditions and characteristics of red clay, red, yellow soil formation in Hungary and in other countries was summarized by 'Sigmond (1934). Red clays possess unique rock characteristics, and shouldn't be confused with other types of rock.

According to Vendl (1957) red clays can be found in the depressions of massive limestone and dolomite. From the uplifted areas the clay material moved into the depressions of the limestone with the rainfall. Under the milder, Mediterranean climate, iron-containing compounds in the clays oxidized and caused the red color of the clay.

Different ideas have been developed about the distribution and characteristics of red clays and loamy products (Vadász 1956, Ötvös 1958, Kretzoi 1969, Bidló 1974, 1985, Jánossy 1979, Jámbor 1980, Borsy and Szöőr 1979-1980, Pécsi 1985, Schweitzer 1993). Stefanovits (1959, 1963, 1967) discovered that the red clays of Hungary are genetically diverse.

Some authors draw parallels between red clay formation and the process of bauxite formation (Vendl 1957) or considered red clays to be the weathering product of bauxite (Vadász 1956). Kubiena (1956, 1958) studied the formation of red clays thoroughly. In his opinion red clay soils are the products of different processes. He called the two main processes of formation: lateritization and rubefication.

While lateritization is associated with the mobilization and washing away of silicic acid, rubefication is the process whereby the iron hydrous oxides coagulate within a short time after the dissolution of iron from primary minerals. He explains the difference at the micro-morphological level. Bárdossy and Aleva (1990) also distinguished bauxite, bauxitic clay and terra rossa. He considered bauxite to be a product of soil formation as well, which could develop in situ or be the result of redeposition.

The FAO World Soil Map also differentiates several types of red soils. As indicated by Driessen and Dudal (1991), Plinthosols and Ferralsols can be characterized by a great amount of mobilizable iron and aluminum compounds, and the similarly red Cambisols (Chromic Cambisols) by relatively moderate weathering. There is a fundamental difference between these two directions of soil formation, also with regard to the clay mineral composition. While Plinthosols and Ferralsols primarily contain kaolinite, the presence of illite is revealed in Cambisols amongst other weathering materials (Fekete 1988). In the recent FAO soil classification (1994) discussing Alisoles, „red montmorillonitic" soil formations, are mentioned which could be classified as tropical red clays.

According to the literature there are major differences, concerning the conditions of formation and the characteristics of red soils and red clays. These issues are further complicated by the influence of changing climatic conditions and the shifting of certain red clay areas due to plate tectonics and crustral movements.

Hungarian red clays differ greatly in their genesis and their physical and chemical characteristics from the other soils types in the country, and also from red clays found elsewhere (Fekete 1989, 1995, 1998, 2002, Fekete et al. 1997, Fekete and Stefanovits 2002). We would like to add to and clarify the understanding of red clays by undertaking a more detailed study into their distinguishing characteristics and common features, which may also assist in evaluating their economic value. Red clays in Hungary are similar to the tropical and sub-tropical ferrolite soils regarding their formation and mineral characteristics. One of our aims is to explore the similarities in processes and characteristics, which would substantially help in classification. In this paper we report the results of soil studies carried out on red clays and soils in Hungary.

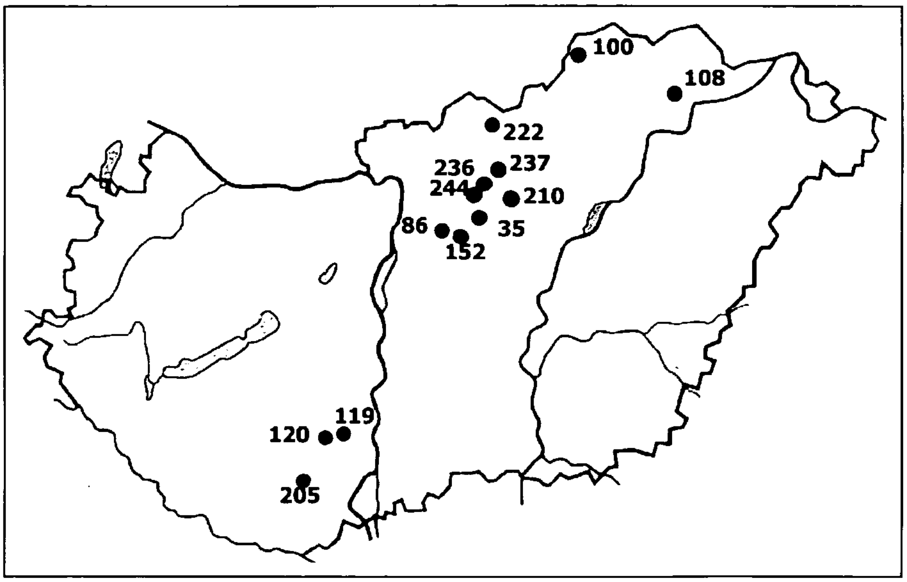


*Fig. 1.* Sites of red clay samples.

*Table 1.* Sampling sites of red clay samples.

| Number and locality | | Depth (cm) | Region | |
|---|---|---|---|---|
| Red clays in Northern Hungary | | | | |
| 100. | Jósvafő | 20 -55 | Northern-Central Mountains | Aggtelek karst (limestone) |
| 108. | Mád | 40 - 60 | Foreland of Northern-Central Mountains | Tokaj Mountains rhyolite tuff |
| 222. | Salgótarján | 400 - 450 | | Northern-Hungary Basin |
| 237. | Mátrakeresztes | 200 - 230 | | Mátra Mountains (alluvial-237. andesite-210, 236) |
| 210. | Gyöngyöstarján | 20 - 40 | | |
| 236. | Muzsla | 10 - 30 | | |
| 244. | Szurdokpüspöki | 350 -380 | | |
| 35. | Hatvan | 50 - 67 | | |
| 152. | Valkó | 260 - 290 | | Gödöllő Hills |
| 86. | Gödöllő | 30 - 60 | | |
| Red clays in Transdanubia | | | | |
| 119. | Szekszárd | 70 - 80 | Transdanubian Hills | Szekszárd Hills (Tertiary-Quaternary loam. clay) |
| 120. | Kakasd | 60 - 80 | | |
| 205. | Kővágószőlős | 8 - 15 | | Mecsek Mountains (Perm. sandstone) |

## MATERIALS AND METHODS

We collected samples from nearly two hundred soil profiles from different parts of the Northern-Central Hill District (Északi középhegység) and Transdanubian Hills (Dunántúli középhegység). From the numerous samples we present results from 13 soil profiles in our study (Fig. 1). Samples were selected to represent the different types and sources of red clays. Samples were collected from the following locations to present the physical and chemical features of red clay and its mineral composition (Table 1).

Basic soil analyses were carried out according to the methodology laid down in the National Methodological Handbook (Buzás 1993).

Mechanical composition was determined by pipette analysis; the cation exchange capacity and the adsorption capacity were determined by the Mehlich method (Buzás 1988).

Chemical analysis of the soil's mineral fraction was carried out according to Szücs (In: Ballenegger and di Gléria 1962) and also by the modified Maul method (1965).

X-ray diffraction and (derivatographic) thermal analysis were applied to determine the mineral composition of the samples by G. Bidló, M. Földvári and P. Kovács-Pálffy.

The micromorphological studies were performed by G. Szendrei. Thin sections were prepared by the method of diluted polyester resin impregnation. The micromorphological features were described according to the Handbook for soil thin section description (Bullock et al. 1985).

## ANALYTICAL RESULTS

The results of the basic soil analyses are shown in Table 2, data on the mechanical composition of the soils is represented in Table 3, the cation exchange capacities and adsorption capacity values are shown in Table 4, results of the total chemical analyses are recorded in Table 5, the mineral composition of the original soil and sieved fractions are shown in Table 6, and some of the micromorphological features are given in Table 7.

*Basic soil analysis*

The soil texture varies between medium-heavy silt and heavy clay. The clay content is significantly high, although in red clays its dispersion is also high. The most probable reason is that most of the studied soils now do not occur there where they were originally formed, but were subsequently transported and became mixed with other sediments (Table 2 and Table 3). Differences observable in the composition of soil particles are accounted for admixture of windblown sediment during the last glacial period. The higher proportion of the loess fraction allows the above mentioned conclusion for the following samples: 108-Mád (31%), 152-Valkó (35%), 205-Kövágószőlős (15%). It is important to note the relationship between particle size composition and other physical soil characteristics.

***Table 2.*** Results of basic soil analysis.

| No. | Locality | Depth (cm) | $K_A$ | $hy_1$ | pH KCl | pH $H_2O$ | $CaCO_3$ (%) | Humus (%) |
|---|---|---|---|---|---|---|---|---|
| | Red clays in Northern Hungary | | | | | | | |
| 100. | Jósvafő | 20 - 55 | 62.00 | 9.72 | 4.74 | 5.92 | 0.00 | 0.19 |
| 108. | Mád III | 40 - 60 | 41.00 | 5.73 | 6.12 | 6.79 | 0.00 | 0.92 |
| 222. | Salgótarján | 400 - 450 | 56.00 | 3,60 | 4.72 | 5.72 | 0.00 | 0.83 |
| 237. | Mátrakeresztes | 200 - 230 | 68.00 | 7.50 | 5.28 | 6.69 | 0.00 | 2.60 |
| 210. | Gyöngyöstarján | 20 - 40 | 93.00 | 5,80 | 6.60 | 7.43 | 0.04 | 1.97 |
| 236. | Muzsla | 10 - 30 | 51.00 | 3.90 | 6.86 | 7.59 | 0.74 | 2.34 |
| 244. | Szurdokpüspöki | 350 - 380 | 53.00 | 2.80 | 3.77 | 5.12 | 0.00 | 0.32 |
| 35. | Hatvan | 50 - 67 | 96.00 | 9.42 | 7.38 | 8.38 | 0.45 | 0.12 |
| 152. | Valkó | 260 - 290 | 47.00 | 4.70 | 7.24 | 8.15 | 6.32 | 1.08 |
| 86. | Gödöllő | 30 - 60 | 58.00 | 3,70 | 3.48 | 4.65 | 0.00 | 1.46 |
| | Red clays in Transdanubia | | | | | | | |
| 119. | Szekszárd | 70 -80 | 57.00 | 4.18 | 7.81 | 8.36 | 4.14 | 1.12 |
| 120. | Kakasd | 60 - 80 | 51.00 | 3.73 | 7.74 | 8.36 | 0.00 | 0.18 |
| 205. | Kővágószőlős | 8 - 15 | 50.00 | 3,48 | 3.50 | 4.67 | 0.00 | 2.66 |

***Table 3.*** Mechanical composition of the soil samples.

| No. | Locality | Depth (cm) | Percentage of particle fractions | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | >0.25 | 0.25–0.05 | 0.05–0.01 | 0.01–0.005 | 0.005–0.001 | <0.001 | >0.01 | <0.01 |
| | Red clays in Northern Hungary | | | | | | | | | |
| 100. | Jósvafő | 20 - 55 | 0.64 | 0.00 | 20.17 | 6.76 | 13.29 | 59.14 | 20.81 | 79.19 |
| 108. | Mád III | 40 - 60 | 0.87 | 8.72 | 31.07 | 2.00 | 1.20 | 45.15 | 40.65 | 59.35 |
| 222. | Salgótarján | 400 - 450 | 3.57 | 9.74 | 24.43 | 9.15 | 9.62 | 43.50 | 37.73 | 62.27 |
| 237. | Mátrakeresztes | 200 - 230 | | | | | | | | |
| 210. | Gyöngyöstarján | 20 - 40 | 1.47 | 0.40 | 13.75 | 9.17 | 20.06 | 55.14 | 15.63 | 84.37 |
| 236. | Muzsla | 10 - 30 | | | | | | | | |
| 244. | Szurdokpüspöki | 350 - 380 | | | | | | | | |
| 35. | Hatvan | 50 - 67 | 8.74 | 4.93 | 15.42 | 17.76 | 21.43 | 31.72 | 29.09 | 70.91 |
| 152. | Valkó | 260 - 290 | 0.58 | 4.23 | 35.03 | 3.42 | 13.44 | 43.30 | 39.84 | 60.16 |
| 86. | Gödöllő | 30 - 60 | 5.89 | 20.91 | 18.35 | 0.23 | 7.77 | 46.85 | 45.15 | 54.85 |
| | Red clays in Transdanubia | | | | | | | | | |
| 119. | Szekszárd | 70 -80 | 0.12 | 0.61 | 35.06 | 5.68 | 11.15 | 47.38 | 35.79 | 64.21 |
| 120. | Kakasd | 60 - 80 | 1.17 | 41.10 | 5.48 | 1.57 | 3.89 | 46.79 | 47.75 | 52.25 |
| 205. | Kővágószőlős | 8 - 15 | 31.03 | 7.07 | 14.79 | 9.20 | 0.15 | 37.77 | 52.88 | 47.12 |

***Table 4.*** Adsorption capacity and exchangeable cations of red clays.

| No. | Locality Site | Depth (cm) | $Ca^{2+}$ (meq / 100g) | $Mg^{2+}$ (meq / 100g) | $Na^+$ (meq / 100g) | $K^+$ (meq / 100g) | Value of S (meq / 100g) | CEC (Value of T) (meq / 100g) | V (S/T*100) (%) | $Ca^{2+}$ (S %) | $Mg^{2+}$ (S %) | $Na^+$ (S %) | $K^+$ (S %) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Red clays in Northern Hungary | | | | | | | | | | | | |
| 100. | Jósvafő | 20 - 55 | 11.43 | 5.60 | 0.31 | 0.29 | 17.63 | 17.63 | 100.00 | 64.83 | 31.76 | 1.76 | 1.65 |
| 108. | Mád III | 40 - 60 | 13.40 | 11.30 | 0.00 | 0.15 | 24.85 | 26.98 | 92.11 | 53.92 | 45.47 | 0.00 | 0.61 |
| 222. | Salgótarján | 400 - 450 | 12.10 | 5.70 | 1.10 | 0.26 | 19.16 | 24.01 | 79.80 | 63.15 | 29.74 | 5.74 | 1.37 |
| 237. | Mátrakeresztes | 200 - 230 | 40.63 | 8.97 | 0.10 | 0.50 | 50.20 | 50.20 | 100.00 | 80.94 | 17.87 | 0.20 | 1.00 |
| 210. | Gyöngyöstarján | 20 - 40 | 36.53 | 4.50 | 0.80 | 0.44 | 42.27 | 42.27 | 100.00 | 86.42 | 10.64 | 1.89 | 1.05 |
| 236. | Muzsla | 10 - 30 | 29.35 | 7.31 | 0.10 | 0.64 | 37.40 | 37.40 | 100.00 | 78.48 | 19.55 | 0.27 | 1.71 |
| 244. | Szurdokpüspöki | 350 - 380 | 11.21 | 6.47 | 0.08 | 0.55 | 18.31 | 28.10 | 65.16 | 61.22 | 35.34 | 0.44 | 3.00 |
| 35. | Hatvan | 50 - 67 | 10.50 | 29.00 | 2.60 | 0.93 | 43.03 | 44.45 | 96.81 | 24.41 | 67.39 | 6.04 | 2.16 |
| 152. | Valkó | 260 - 290 | 16.32 | 3.70 | 0.05 | 0.35 | 20.42 | 20.42 | 100.00 | 79.92 | 18.12 | 0.24 | 1.72 |
| 86. | Gödöllő | 30 - 60 | 6.53 | 10.00 | 0.67 | 0.43 | 17.63 | 17.63 | 100.00 | 37.04 | 56.72 | 3.80 | 2.44 |
| | Red clays in Transdanubia | | | | | | | | | | | | |
| 119. | Szekszárd | 70 - 80 | 6.52 | 7.10 | 0.20 | 5.60 | 19.42 | 19.42 | 100.00 | 33.57 | 36.56 | 1.03 | 28.80 |
| 120. | Kakasd | 60 - 80 | 6.75 | 6.40 | 0.20 | 0.40 | 13.75 | 13.75 | 100.00 | 49.09 | 46.54 | 1.45 | 2.92 |
| 205. | Kővágószőlős | 8 - 15 | 5.90 | 0.00 | 0.05 | 0.31 | 6.26 | 12.00 | 52.17 | 94.24 | 0.00 | 0.79 | 4.97 |

***Table 5.*** Results of the chemical analysis of red clays

| No. | Locality Site | Depth (cm) | $SiO_2$ % (In the total sample) | $Al_2O_3$ % (In the total sample) | $Fe_2O_3$ % (In the total sample) | $\frac{SiO_2}{R_2O_3}$ (In the total sample) | $\frac{Al_2O_3}{Fe_2O_3}$ (In the total sample) | $SiO_2$ % (In the fine fraction) | $Al_2O_3$ % (In the fine fraction) | $Fe_2O_3$ % (In the fine fraction) | $\frac{SiO_2}{R_2O_3}$ (In the fine fraction) | $\frac{Al_2O_3}{Fe_2O_3}$ (In the fine fraction) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Red clays in Northern Hungary | | | | | | | | | | | |
| 100. | Jósvafő | 20 - 55 | 50.99 | 19.54 | 6.13 | 3.71 | 5.03 | 36.41 | 30.03 | 8.78 | 1.74 | 5.37 |
| 108. | Mád III | 40 - 60 | 58.21 | 14.07 | 4.56 | 5.84 | 4.93 | 40.09 | 20.79 | 9.22 | 2.56 | 3.54 |
| 222. | Salgótarján | 400 - 450 | | | | | | 49.84 | 19.85 | 7.33 | 3.46 | 4.25 |
| 237. | Mátrakeresztes | 200 - 230 | | | | | | 59.39 | 28.01 | 10.20 | 2.93 | 4.31 |
| 210. | Gyöngyöstarján | 20 - 40 | 60.31 | 17.27 | 7.61 | 4.57 | 3.63 | 50.33 | 21.41 | 4.70 | 3.51 | 7.14 |
| 236. | Muzsla | 10 - 30 | | | | | | 48.88 | 27.24 | 13.64 | 2.31 | 3.13 |
| 244. | Szurdokpüspöki | 350 - 380 | | | | | | 50.77 | 21.41 | 9.34 | 3.15 | 3.60 |
| 35. | Hatvan | 50 - 67 | 59.48 | 18.80 | 4.61 | 4.65 | 6.34 | 49.64 | 21.34 | 6.98 | 3.27 | 4.80 |
| 152. | Valkó | 260 - 290 | 63.32 | 22.36 | 4.56 | 4.86 | 7.82 | 53.20 | 18.49 | 7.49 | 3.89 | 3.87 |
| 86. | Gödöllő | 30 - 60 | 67.77 | 13.33 | 3.10 | 7.52 | 6.89 | 39.25 | 23.97 | 8.34 | 2.28 | 4.51 |
| | Red clays in Transdanubia | | | | | | | | | | | |
| 119. | Szekszárd | 70 -80 | 55.76 | 30.36 | 4.97 | 2.99 | 9.76 | 37.35 | 23.70 | 9.07 | 2.15 | 4.18 |
| 120. | Kakasd | 60 - 80 | 66.96 | 12.62 | 4.35 | 7.39 | 4.64 | 38.40 | 26.64 | 8.56 | 2.03 | 4.98 |
| 205. | Kővágószőlős | 8 - 15 | 69.60 | 13.62 | 3.93 | 7.34 | 5.56 | 48.01 | 25.80 | 6.36 | 2.73 | 6.48 |

The plasticity value is in accordance with the hygroscopic value. The highest hygroscopic values were detected in samples 100-Jósvafő, 210-Gyöngyöstarján, 35-Hatvan (Table 2).

Chemical reaction (pH) is a little bit acid, but some samples have neutral or alkaline chemical reaction, because they contain CaCO3. The humus content is generally low.

*Adsorption capacity and exchangeable cations*

The adsorption capacity of red clay soils appears to be related with the clay content and the mineral composition of the clay. Due to the large amount of the clay fraction high CEC (value of T) would be expected, but the values measured were generally low (Table 4). High cation exchange capacity (CEC) values are recorded in soils with high clay content. In the samples where the adsorption capacity values are lower, we can find mainly kaolinite. The cation exchange capacity value is varying from 12 to 44 meq/100g. In samples 35-Hatvan, 210-Gyöngyöstarján the CEC values are the highest, above 40 meq/100g. The V values indicate saturation, except for 205-Kövágószőlős (this sample has only 52% V), because this soil was formed on the Permian sandstone.

The Ca and Mg ions are dominant among the exchangeable cations. The Ca ion S%-values in some samples are 60 – 80 %, and the Mg ion S%-values in the range 45 – 67% are in the samples: 35-Hatvan, 86-Gödöllő, 108-Mád, 120-Kakasd.

*Table 6.* Mineral composition of red clay samples (%). O*original sample. ff** fine fraction

| | Northern Hungary | | | | | | | | | | | | | | | | | | | | Transdanubia | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minerals | Jósvafő (100) | | Mád (108) | | Salgótarján (222) | | Mátrakeresztes (237) | | Gyöngyöstarján (210) | | Muzsla (236) | | Szurdokpüspöki (244) | | Hatvan (35) | | Valk (152) | | Gödöllő (86) | | Szekszárd (119) | | Kakasd (120) | | Kővágószőlős (205) | |
| | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** | O* | ff** |
| Quartz | 59.5 | 37.2 | 32.3 | 28.1 | - | 44.0 | - | 30.0 | - | 23.0 | 33.2 | 21.6 | 29.8 | 13.0 | - | 56.0 | - | 16.7 | 71.6 | 30.1 | 33.2 | 21.6 | 29.8 | 13.0 | - | 56.0 |
| Calcite | 2.7 | - | - | 1.3 | - | - | - | - | - | - | 2.7 | 10.6 | 1.1 | - | - | - | - | 1.4 | 3.8 | 5.8 | 2.7 | 10.6 | 1.1 | - | - | - |
| Dolomite | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 3.0 | - | - | - | 0.6 | - | - | - | - | - | 3.0 |
| Feldspars | 2.0 | 2.0 | 1.5 | 13.1 | - | 10.0 | - | 11.0 | - | 7.0 | 3.5 | 4.7 | 10.2 | 6.3 | - | 7.0 | - | 8.9 | 1.7 | 4.1 | 3.5 | 4.7 | 10.2 | 6.3 | - | 7.0 |
| Kaolinite | 28.5 | 30.7 | 2.0 | 8.1 | - | - | - | 1.0 | - | 2.0 | 5.3 | 14.8 | 26.0 | 19.4 | - | - | - | 9.3 | 11.5 | 9.5 | 5.3 | 14.8 | 26.0 | 19.4 | - | - |
| Chlorite | - | - | - | - | - | 2.0 | - | - | - | - | 51.1 | 10.6 | 10.6 | 4.0 | - | 2.0 | - | 1.6 | - | - | 51.1 | 10.6 | 10.6 | 4.0 | - | 2.0 |
| Illite | - | - | - | - | - | 6.0 | - | 2.0 | - | - | - | - | - | - | - | 12.0 | - | - | - | - | - | - | - | - | - | 12.0 |
| Illite/Mon. | - | - | - | - | - | 5.0 | - | 1.0 | - | - | - | - | - | - | - | 3.0 | - | - | - | - | - | - | - | - | - | 3.0 |
| Illite+mica | - | - | 32.8 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 37.9 | - | 1.9 | - | - | - | - | - | - |
| Montmorill. | - | - | - | - | - | 24.0 | - | 47.0 | - | 50.0 | - | - | 16.4 | - | - | 8.0 | - | - | - | - | - | - | 16.4 | - | - | 8.0 |
| Mo+amorphous | - | 23.2 | 25.0 | 42.8 | - | - | - | - | - | - | - | 32.0 | - | 48.9 | - | - | - | 4.6 | 5.6 | 40.0 | - | 32.0 | - | 48.9 | - | - |
| Muscovite | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Gibbsite | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.8 | - | - | - | - | - | - | - | - |
| Hematite | 0.8 | 0.5 | - | - | - | 2.0 | - | 5.0 | - | 12.0 | - | - | - | 0.8 | - | - | - | 1.1 | - | - | - | - | - | 0.8 | - | - |
| Goethite | - | - | - | - | - | 3.0 | - | - | - | - | - | - | - | - | - | 5.0 | - | - | - | - | - | - | - | - | - | 5.0 |
| Humus | 2.1 | 2.0 | 1.4 | 1.4 | - | - | - | - | - | 1.0 | 1.0 | 1.5 | 0.8 | 1.0 | - | - | - | 1.2 | 1.2 | 1.6 | 1.0 | 1.5 | 0.8 | 1.0 | - | - |
| Amorphous | - | - | - | - | - | 4.0 | - | 5.0 | - | 6.0 | - | - | - | - | - | 4.0 | - | 7.3 | 7.3 | - | - | - | - | - | - | 4.0 |
| $H_2O^-$ | 3.20 | 3.6 | 4.4 | 4.0 | - | - | - | - | - | - | 3.2 | 4.2 | - | - | - | - | - | 3.8 | 4.0 | 5.4 | 3.2 | 4.2 | - | - | - | - |
| $H_2O^+$ | 1.20 | 0.8 | 0.6 | 1.2 | | | | | | | | | | | | | | 1.2 | 0.6 | 1.0 | | | | | | |

*Chemical analysis*

The data of total chemical analyses were considered important both in order to identify the age of soils, and also to judge the weathering characteristics. The SiO2/R2O3 molecular ratio refers to the nature of weathering. From the total chemical analyses we present here the SiO2, Al2O3 and Fe2O3 values in percentage and their ratios for both the total samples and for the clay fraction (Table 5). Depending on the quality and structure of the clay minerals, the data indicate that in the samples the percentage of SiO2 is higher while in the clay fraction the values of Al2O3 and Fe2O3 are higher.

Based on the molecular ratios the samples can be subdivided into the following genetic groups:

- In the sample 100-Jósvafő the weathering intensity is as strong, as in tropical ferrallitic soils. This intensity can be observed in the low SiO2/Al2O3-ratio, this number is 1.74 in the clay fraction. Similarly tropical weathering is indicated in the following samples: 236-Muzsla, 86-Gödöllő, 108-Mád, 119-Szekszárd, 120-Kakasd, where the SiO2/R2O3-ratio of the clay fraction is near to 2, or a little bit higher. The Al2O3/Fe2O3-ratio of these samples are in the range 3.1 – 4.9%. According to the mineralogical analysis of these samples (Table 6) kaolinite content is significant, but we can find montmorillonite as well (236-Muzsla). All that indicates slightly ferrallitic weathering.
- In conform with Al2O3/Fe2O3-ratio (5.37) the weathering is allitic (bauxitic) in sample 100-Jósvafő. We can find tropical soil features like kaolinite and hematite contents in this sample.
- In the samples: 222-Salgótarján, 237-Mátrakeresztes, 244-Szurdokpüspöki, 35-Hatvan, 152-Valkó, the weathering is siallitic, considering that the SiO2/R2O3-ratio is in the range 3- 4. Kaolinite is very few, but montmorillonite (10-47) is significant. We can find the samples mentioned above in the Mátra Mts., and in Mátra Foothills, region at the Northern Periphery of the Hungarian Plain. These samples are red clays, but there is also loess involved. In this case the resulting chemical composition shows siallitic weathering.

***Table 7.*** Micromorphological features of clay components in red clays

| Sample | | b(birefringence)-fabric | | | | Pedological features clay/ferruginous clay | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Locality | undifferentiated/ masked b-fabric | mosaic speckled | striated | granostriated | frequency | homogeneous | heterogeneous | coating | infilling | hypocoating | papule |
| Red clays in Northern Hungary | | | | | | | | | | | | |
| 100. | Jósvafő | | x | x | x | vc | | | x | x | x | |
| 108. | Mád | | x | x | x | c | x | | x | x | | x |
| 222. | Salgótarján | | | | (x) | c | | | x | x | | x |
| 237. | Mátrakeresztes | | x | x | x | vr | | | | x | | |
| 210. | Gyöngyöstarjá | | | x | x | vr | x | | | x | | |
| 236. | Muzsla | | x | x | x | c | x | | x | x | x | x |
| 244. | Szurdokpüspök | | x | x | x | vr | | | x | | x | (x) |
| 35. | Hatvan | | | | (x) | vc | x | | x | x | | |
| 152. | Valkó | | x | | x | c | x | | x | x | x | x |
| 86. | Gödöllő | | | | (x) | vr | | | x | x | | |
| Red clays in Transdanubia | | | | | | | | | | | | |
| 119. | Szekszárd | | x | x | x | | | | | | | |
| 120. | Kakasd | | x | x | x | | | | | | | |
| 205. | Kővágőszőlős | | x | x | x | vc | | x | x | x | | |

Legend: vr – very rare; r – rare; c – common; vc – very common.

- In the sample 205-Kövágószőlős the weathering is siallitic, because the soil was formed on Permian sandstone.

It is likely that those soils (red clays) with higher SiO2/R2O3-ratios have resulted from previous tectonic inversion and surface redeposition processes, and have thus mixed composition of various products of weathering.

*Mineralogy*

The examination of the mineral composition (Table 6.) by thermal analysis and X-ray diffraction is of decisive importance in identifying the age and weathering processes of red clays and also in assessing numerous characteristics about these clays.

Table 7. presents the micromorphological features of clay components. In the red clays of the Northern Periphery of the Hungarian Plain micromorphological features of clay mobilization can be found in the groundmass (speckled, granostriated) in varying degree as well as along the pores (coatings, hypocoatings and infillings) with different frequency. Samples: 35-Hatvan; 152-Valkó.

In the red clay of Aggtelek Karst micromorphological features of clay mobilization were observed in the groundmass (speckled, granostratied, monostriated) and along the pores (coatings, hypocoatings and infillings) indicating stresses in this sample: 100-Jósvafő.

In the red clays of the foothills of the Tokaj Mountains: micromorphological features recognized are pronounced in the groundmass (speckled, granostratied, monostriated) and along the pores (coatings and infillings) indicating clay mobilization. Sample: 108-Mád.

Red clays formed by the weathering of the Pannonian surface: Speckled, granostriated and monostriated b-fabrics were only recognized. Clay coatings and infillings were absent probably due to the calcite content. Sample: 119-Szekszárd.

Red soils formed on Permian sandstone: Well marked micromorphological features indicating mobilization of clay particles in the groundmass (speckled, granostriated, monostriated) and along the pores (coatings and infillings) were observed. Sample: 205-Kővágószőlős.

The speckled and granostratied b-fabric of the groundmass, whose occurrence is mainly due to swelling and shrinking, was observed in samples

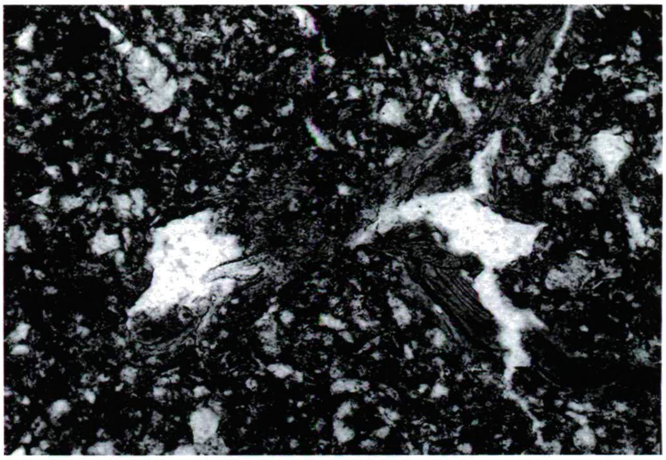

*Fig. 2.* Photomicrograph: ferruginous clay infilling in red clay. Transmitted light, 114x. 108-Mád, Tokaj Mountains.

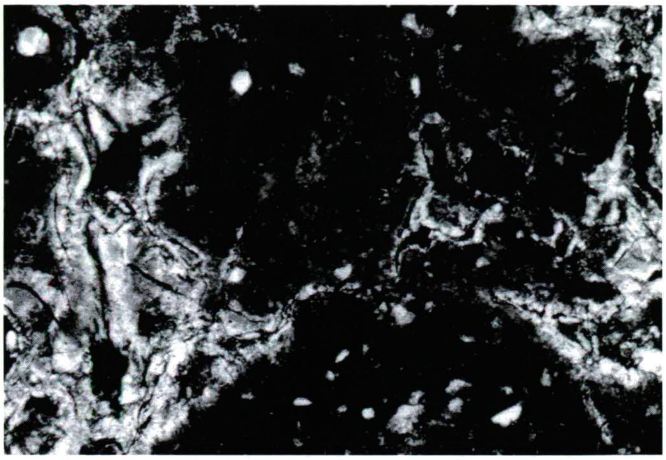

*Fig. 4.* Photomicrograph: Clay infilling in red clay. Transmitted light, 59x. 35-Hatvan, Gödöllő Hills.

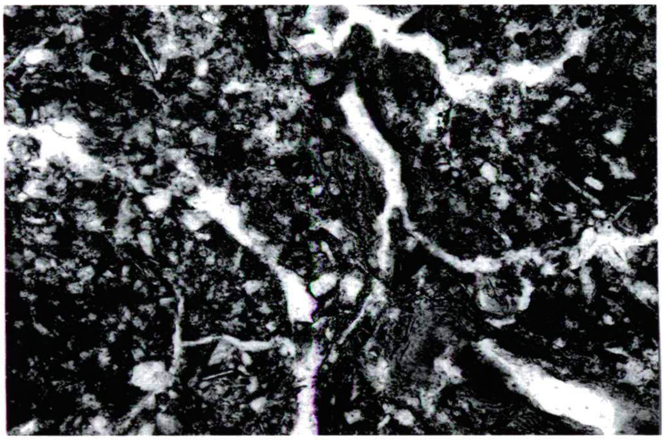

*Fig. 3.* Photomicrograph: ferruginous clays coatings and infillings in red clay. Transmitted light, 114x. 236-Muzsla, Mátra Mountains.

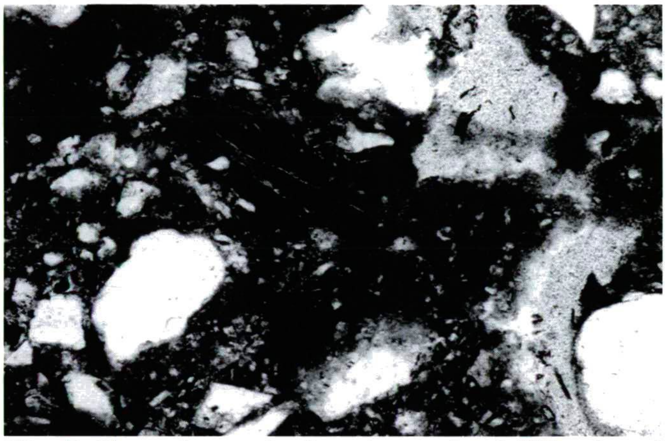

*Fig. 5.* Photomicrograph: ferruginous clay infilling in red clay. Transmitted light, 59x. 205 - Kővágószőlős, Mecsek Mountains.

from the sites: 86-Gödöllő, 210-Gyöngyöstarján, 35-Hatvan, 100-Jósvafő, 120-Kakasd, 205-Kővágószőlős, 108-Mád, 237-Mátrakeresztes, 236-Muzsla, 222-Salgótarján, 119-Szekszárd, 244-Szurdokpüspöki and 152-Valkó. Swelling was confirmed by the occurrence of stress coatings in the red clays from 100-Jósvafő and 244-Szurdokpüspöki.

Occurrences of clay coatings in samples of sites in Fig. 2.: 108-Mád; Fig. 3.: 236-Muzsla; Fig. 4.: 35-Hatvan; Fig. 5.: 205-Kővágószőlős; Fig. 6.: 152-Valkó; 237-Mátrakeresztes, 222-Salgótarján, 244-Szurdokpüspöki and 86-Gödöllő. They were interpreted as micromorphological features of illuviation.

Illuviation coatings and infillings were observed most often in samples from 35-Hatvan-Gombos and 205-Kővágószőlős.

Traceable striated birefringence fabric was also observed in Quaternary paleosol in the pediment of Mátra Mountains. Clay coatings were also found in Quaternary paleosol in the foothills of Mátra Mountains (Visonta) /Berényi-Üveges et al. 2003/.

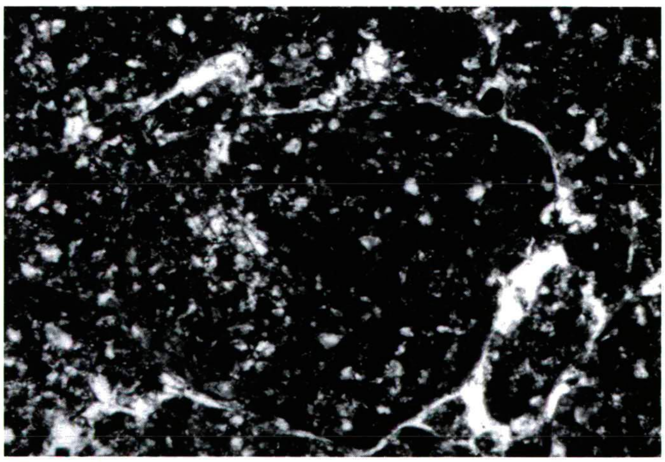

*Fig. 6.* Photomicrograph: Rounded aggregate with ferruginous clay coating. Transmitted light, 59x. 152-Valkó, Gödöllő Hills.

## CONCLUSION

On the basis of pedological and mineral analysis the red clays of Hungary can be ranked in various groups:

1. Red soils formed on the Permian sandstone: Clay on the surface of Permian red sandstone do not contain kaolinite and hematite, but contain goethite. Sample: 205-Kövágószőlős. Their colour is red, sporadically with a purple nuance. They are rocks formed from a mixture of sediments and tropical red soils. Naturally, the soil formed on the Permian bedrock is not remnant of a Paleozoic soil, but is a relic soil and originates from the end of the Tertiary Period. The signs of

the oldest soil formation in Hungary can probably be found in the Permian red sandstone.

2. Red clays of Pannonian surface: In the Transdanubian Hills the red clays have been produced by weathering of the Pannonian surface. We can find illite, chlorite, montmorillonite and kaolinite. Samples: 119-Szekszárd, 120-Kakasd. They were formed between the end of the Miocene Period and the lower Pleistocene.

3. Red clays formed on the rhyolite tuff: The red clays of Tokaj foothills, formed on rhyolite tuff with low amount of kaolinite and 40% montmorillonite in the fine fraction. Sample: 108-Mád. They were formed on rhyolite or rhyolite tuff, and are covered by loess in some areas. They are relic soils, older than loess, formed under the warm climate of the Tertiary Period.

4. The red soils of Aggtelek karst, Torna hills: In these clays the kaolinite content are 30%. Sample: 100-Jósvafő. These soils were very heavy soils with significant clay content. They are Tertiary relic soils formed on Mesozoic limestone. Laterite and bauxite formations can be detected in some places.

5. The red clays in the Mátra Mountains and foothills: In these samples there is significant quantity (20 – 50%) of montmorillonite. Sample: 222-Salgótarján, 236-Muzsla, 244-Szurdokpüspöki can be characterized by a few chlorite. There is no chlorite in samples 210-Gyöngyöstarján and 237-Mátrakeresztes. We can find low hematite contents (1 – 12%).

6. The red soils of Northern Periphery of the Hungarian Plain with significant amount of montmorillonite, and 10% to 20% kaolinite. Samples: 35-Hatvan, 152-Valkó, 86-Gödöllő. These soils have medium clay content. They are situated on clay, silt and sand layers of different origin or between loess depositions. They were formed in the Pliocene and at the turn of the Pliocene and Pleistocene.

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