Clay minerals as indicators of the soil substrate origin of Rendzinas (Rendzic Leptosols) from the Małopolska Upland (S Poland)

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Abstract
Mineralogical (XRD) and micromorphological studies have show that clay mineral species can indicate the origin of the clay material in soils developed from limestones (Rendzic Leptosols). Smectite is an authigenic clay mineral in soils developed from Cretaceous soft micritic limestones, marls and opokas. Kaolinite is a para-authigenic mineral in soils developed from hard sparitic Devonian and Jurassic limestones. Its presence points to the relict *terra rossa*-type debris covers. Illite is of allogenic origin and indicates the admixture of silicate material from Quaternary glacial deposits. Mineralogical indicators of present-day pedogenesis are mixed-layered minerals (i.e. illite/smectite) present only in the superficial genetic horizons. The obtained results may be widely used in studies on the influence of geomorphologic processes and changing climate on the formation and evolution of soils developed from calcareous rocks.

Key Words
Soil origin, lithogenesis, sandstones, siltstones, clays

Introduction
The study of soils developed from limestones is a wide and ongoing issue. Such soils represent the basic element of specific ecosystems, which in some parts of the world are considered as areas with high natural and economical value. In Poland these soils are referred to as *rędziny* and assigned to lithogenic soils. According to FAO WRB they are Rendzic Leptosols.
The most important topic in the study of soils developed from limestones is the clay fraction. The variety of climatic, lithogenic and pedogenic factors present during soil development from limestones causes to the clay fraction occurring in the soil substrate to attain a specific mineralogical composition. This fact is reflected in the characteristic features and properties of the soils. Some clay minerals play the role of indicators in recognizing the process of soil formation, tracing its evolution and evaluating its usability. This study were focused on determining which clay minerals are indicators in the case of soils developed from limestones of different age located in the Małopolska Upland.

Material and Methods
The study was performed on representative profiles of Rendzinas developed from limestones of different age located in the Małopolska Upland in southern Poland. Samples were collected from characteristic genetic soil horizons and from the limestones. They were next treated according to the standard methods applied in soil science. Mineralogical studies of the clay fraction were made with application of XRD using a D 5000 (Bruker-AXS) apparatus. The clay minerals were classified on the basis of the occurrence of *00l* reflections diffractograms (Brindley and Brown 1980). Additionally, micromorphological analysis was also conducted. The clay fraction distribution was determined in different soil types. Observations were made of thin sections on an Olympus BX-41 polarized microscope (Bullock *et al.* 1985).

Discussion of results
Studies of soils developed from limestones of different age in the Małopolska Upland have show that characteristic clay minerals are present in the silicate substrate (Figure 1). Some of these minerals can be considered as mineralogical indicators determining the origin of the clay material (its autho- or allogenic character) or evaluating later transformations in the pedogenic processes.
Smectite is a indicative mineral for the clay fraction in soils developed from Cretaceous rocks. Its presence points to the strict connection of the non-carbonatic soil substrate with the specific character of the carbonate rocks – soft micritic limestones, marls and marly opokas. This mineral is the prevailing constituent of the clay admixture in Cretaceous rocks in the Małopolska Upland. (Jeans 1968).

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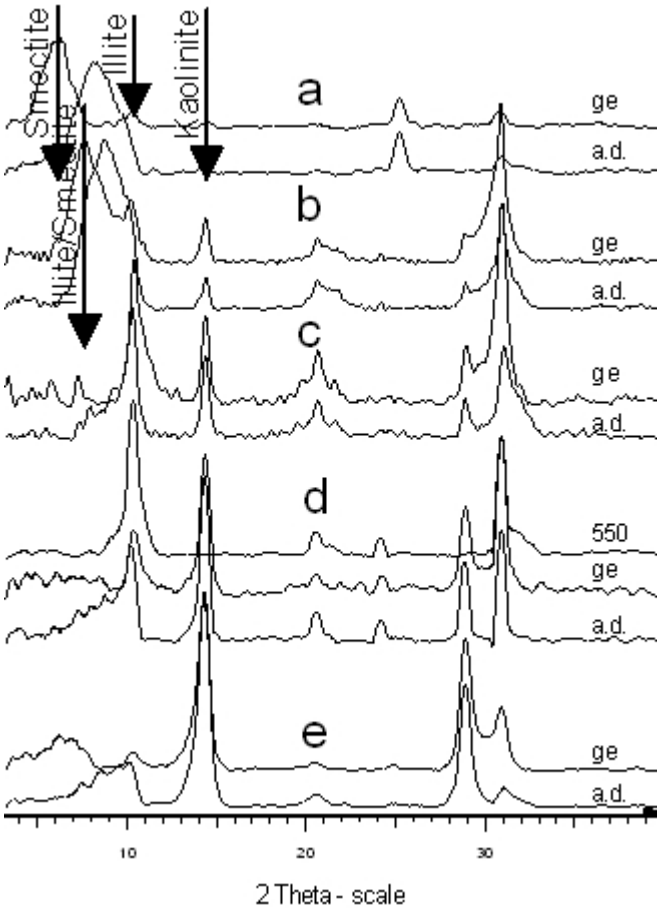

Figure 1. X-ray patterns of clay fraction from different types of Rendzinas. Examples of clay minerals as indicators: a - smectite (soil developed from Cretaceous marls Kije profile, AC horizon); b - mixed layer minerals (soil developed from Tertiary lithothamnium limestone Jablonica profile, A horizon); c - illite (soil developed from Jurassic platy limestone, Bukowno profile AC horizon); d - kaolinite (soil developed from sparitic Devonian limestone, Kowala profile, AC horozon; e - kaolinite (terra rossa developed from Devonian limestone, Posłowice, B(re) horizon)
a.d. air dry specimen; ge - ethylene glycol saturated specimen, 550 - specimen heated at 550˚C.

Micromorphological observations of results of the progressing *in situ* decalcification followed by eluviation show that lithogenic smectite is introduced to the soil substrate as a silicate admixture (Figure 2). In Rendzinas developed from marly opoka, smectite may be concentrated as illuvium with characteristic cutans and fillings of empty voids. Detailed analysis of the micromorphological features and the profile morphology indicates that the accumulation of the clay fraction still continues and to a large degree depends of the type of soil usage, e.g. it is more intense in arable soils. Authigenic smectite is a significant element influencing the physicochemical and physical properties of these soils.

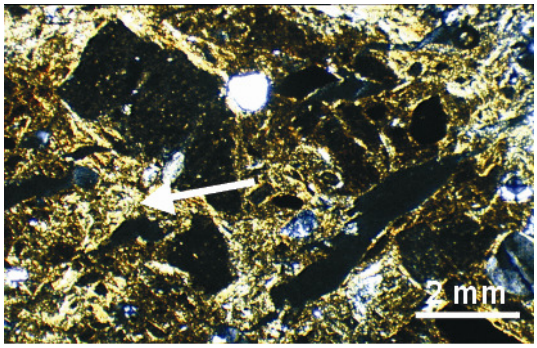

Figure 2. Authigenic (eluvial) clay components. Smectite. Soil developed from Cretaceous opoka, Mnichów profile, horizon BC. Crossed nicols

In Rendzinas developed from hard sparitic Devonian and Jurassic limestones, kaolinite is the mineral indicative of the origin of the clay fraction (Figure 3). Generally it occurs in the basal horizons of soils

located on elevated limestone massives. Kaolinite is a para-authogenic mineral and can be used to evaluate changes of the soil environment over long periods of time. It has a high crystallinity, which indicates that is was formed from a non-carbonate residuum of weathering limestones in a geochemical environment favoring kaolinization, e.g. in warm climate conditions (Konecka-Betley *et al.* 1989). Similar diffraction features were observed in kaolinite from relict horizons that, based on field and micromorphological studies, are considered as fragments of a Tertiary *terra rossa* cover developed on Devonian limestones. The presence of kaolinite in the non-carbonate substrate clearly indicates the connection between soils developed from Devonian and Jurassic limestones with ancient geomorphological processes, particularly Tertiary karst phenomena (Głazek 1989).

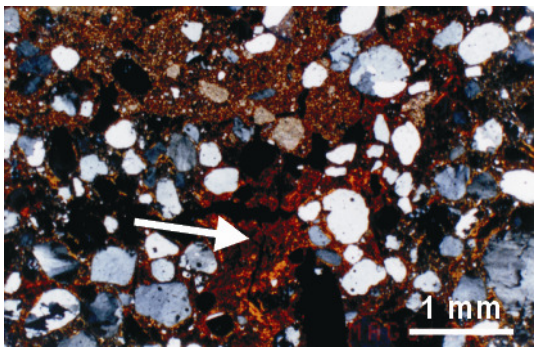

Figure 3. Parauthigenic (residual) clay components. Kaolinite. Soil developed from Jurassic sparitic limestone, Olsztyn profile ABbr horizon. Crossed nicols

A typical allogenic element in the clay material of Rendzinas is illite (Figure 4). It is a significant mineralogical indicator of the soil substrate origin in soils containing a high content of silicate admixture, i.e. the so-called mixed Rendzinas occurring in the low-lying and flat parts of the Małopolska Upland. XRD studies have shown that it contains similar structural features to illite occurring in glacial tills. This means that the non-carbonatic material derives from Quaternary glacial deposits. What is characteristic, allogenic illite occurs not only in the superficial genetic horizons but usually also in the entire soil profile. This testifies for deep mixing, reaching down to the limestone rocks, of the limestone debris with glacial material that took place probably during the advance of the ice-sheet on the Małopolska Upland area during the Pleistocene glaciations.

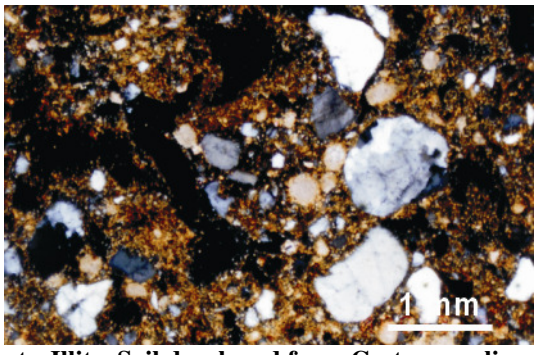

Figure 4. Allogenic clay components, Illite. Soil developed from Cretaceous limestone, Ożarów profile, AC horizon. Crossed nicols

Mineralogical indicators of pedogenesis in minerals composing the clay fraction of the studied Rendzinas are illite/smectite mixed-layered minerals. The presence of such minerals indicates *in situ* chemical and structural transformation of the clay fraction taking place in soils due to pedogenic processes. Detailed analysis of the mixed-layered minerals in particular profiles and genetic horizons shows that in the study area these minerals should be used as indicators only in the superficial A or Ap horizons of soils developed from Cretaceous rocks and containing additionally also allogenic illite. Illite/smectite minerals are generally absent in deeper AC and Cca horizons. This is caused by the fact that leaching is hampered in soils developed from limestones due to high pH and presence of active carbonates, resulting in slow transformation of the clay minerals. This process can speed up in cases when e.g. long-term extensive farming causes continuous removal of the mineral elements from the soil environment. One should consider also the possible add of eolian materials (Priori *et al.* 2008).

Summary

The presented results indicate the significant role of clay minerals in the substrate of soils developed from limestones. Applied as indicatory minerals they may be used to solve the following issues:

- indicating the source of the non-carbonate element in soils;
- explaining some soil properties with regard to the limestone type;
- determining the usability of soils and preventing their degradation.

The obtained data may be widely applied in studies on the influence of climate changes, geomorphological processes and human activities on ecosystems in different parts of the world.

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