19th World Congress of Soil Science

Symposium 1.6.2
Soils in limestone environments

Soil Solutions for a Changing World,

Brisbane, Australia

1 – 6 August 2010

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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).

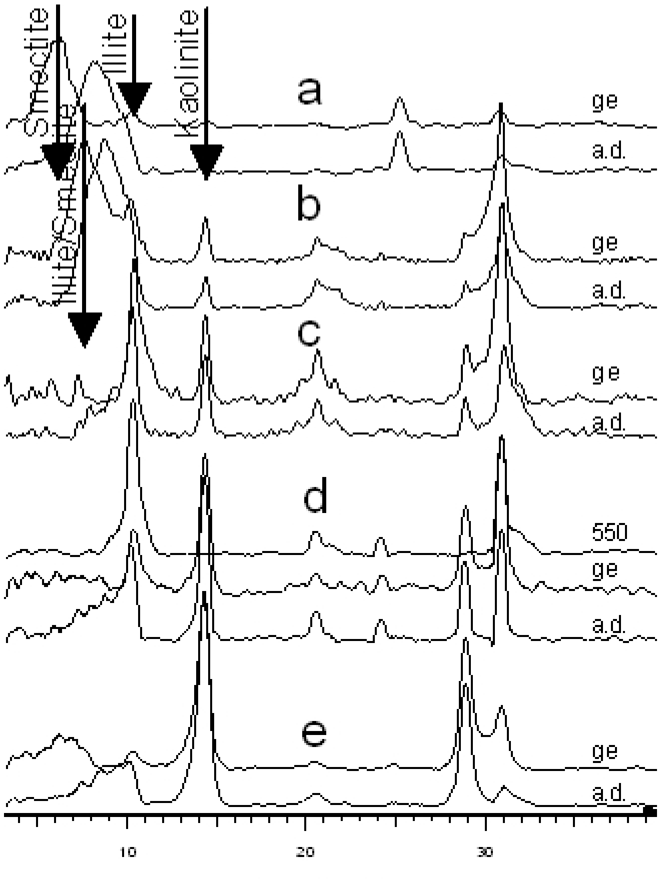

Figure 1. X-ray patterns of clay fraction from different types of Rendzinas. Examples of clay minerals as indicators: a - smectite (soil developed from Cretaceous marls Kije profile, AC horizon); b - mixed layer minerals (soil developed from Tertiary lithothamnium limestone Jablonica profile, A horizon); 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.

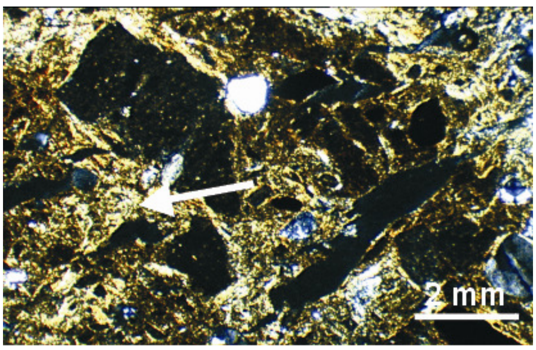

Figure 2. Authigenic (eluvial) clay components. Smectite. Soil developed from Cretaceous opoka, Mnichów profile, horizon BC. Crossed nicols

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).

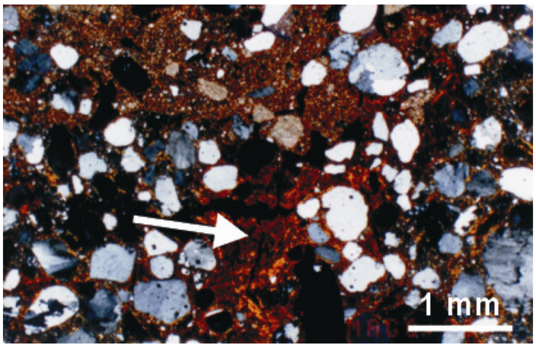

Figure 3. Parauthigenic (residual) clay components. Kaolinite. Soil developed from Jurassic sparitic limestone, Olsztyn profile ABbr horizon. Crossed nicols

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.

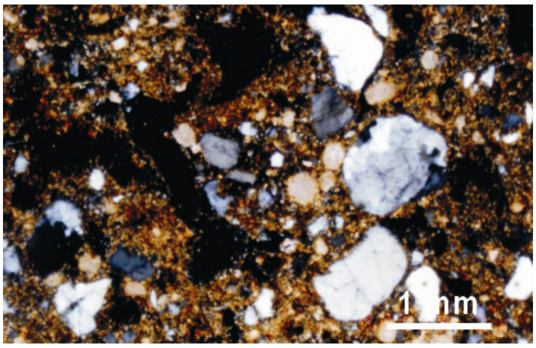

Figure 4. Allogenic clay components, Illite. Soil developed from Cretaceous limestone, Ożarów profile, AC horizon. Crossed nicols

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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Effect of NH_4OH on nematode, fusarium and verticillium wilt infections in tomato

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Abstract
Plant parasitic nematodes are among the most important pests that adversely influence tomato production in Lebanon and its neighboring countries. Fusarium and verticillium wilts also cause severe constraints on agricultural production in the Near East. Two experiments were conducted: A greenhouse pot experiment to estimate toxicity levels of ammonium hydroxide on tomato plants (more than 400 mg NH_4OH/Kg of soil was toxic). A second experiment in a plastic tunnel was conducted to study the effects of Ammonium hydroxide on yield and root galling in tomato plants. Results showed that NH_4OH at a rate of 400 mg NH_4OH/Kg of soil was effective in reducing root galling, fusarium and verticillium wilts and in improving yield.

Key Words
Ammonium hydroxide, root knot nematodes, verticillium wilt, fusarium wilt

Introduction
Plant parasitic nematodes and soil borne diseases such as those caused by *Fusarium* and *Verticillium* pathogens occur worldwide and attack a wide range of crops. In addition, plant parasitic nematodes predispose host plants to be attacked by other soil pathogens leading to disease complexes with other pests. Root knot nematodes (*Meloidogyne spp.*) are considered the most economically important nematode pests attacking tomatoes. *Meloidogyne spp.* are also serious pathogens of many economic crops, including oil plants, vegetables, fruit trees, tea, tobacco, and medicinal plants. Such problems are widely spread in controlled agricultural systems (greenhouse and plastic tunnels) in Lebanon and neighboring countries which necessitate the search for appropriate measures. Chemical control of soil borne diseases, especially root knot nematodes (RKN), is mainly done by methyl bromide fumigation, which is considered the most reliable soil fumigant for the control of soil borne pathogens. However, it has been banned in many countries in the Middle East and will be banned in Lebanon effective 2015, because it is an atmospheric ozone depleting agent (Watson *et al.* 1992). Other products such as: Metam sodium (Vapam), Dazomet (Basamid), Telone and Chloropicrin differ in their effectiveness, weed infestations and toxicity to the environment in general.

The objectives of this study were to investigate the effect of NH_4OH on the occurrence and control of *Meloidogyne*, *Verticillium* and *Fusarium* species in tomato, and to evaluate the yield response for soil applications of NH_4OH treatments in a plastic tunnel.

Materials and methods
Two experiments were conducted. A pot experiment to determine the toxicity levels of ammonium hydroxide on tomatoes and a plastic tunnel experiment to study the effect of ammonium hydroxide on the suppression of soil borne diseases in tomato plants.

Pot Experiment
Plastic pots (15 cm diameter and 1 kg of soil/pot) were used. The different treatments of ammonium hydroxide were placed at a depth of 5 cm from soil surface through a hole as shown in Table 1.

Table 1. Rates of ammonium hydroxide of the pot experiment.

Treatment No.	NH_4OH pre-planting mg/kg	NH_4OH post-planting mg/kg
1	200	-
2	400	-
3	600	-
4	200	100
5	200	200
6	200	400

The pots were left for one week before transplanting and toxicity symptoms were recorded for a period of two months.

Plastic Tunnel Experiment

The experiment was conducted in a plastic tunnel which was previously planted with vegetables (tomato, cucumber, parsley…) for several years without receiving any treatments to control soil born diseases.
The design of the experiment was a completely randomized design (CRD) with five treatments and three replicates. The rates of NH_4OH are shown in Table 2.

Table 2. Rates of NH_4OH of the plastic tunnel experiment.

Treatment No.	Treatment mg/kg	Rate of NH_4OH per Plot mL/m^2
1	400	100
2	200	50
*3	(200+200)	(50+50)
*4	(200+100)	(50+25)
5	CONTROL	CONTROL

*Numbers in brackets: first number is applied pre-planting and second number is   applied post-planting.

Each treatment was 6m^2. Application of NH_4OH was done one week prior to transplanting .A soluble fertilizer N-P-K (20-20-20+T.E.) was applied via irrigation system to all plots at the same rates.
Soils samples from beside the roots were collected twice a week to perform nematode counts and to identify the infestation severeness of *Verticillium* and *Fusarium* wilts. Furthermore, in mid-season, a plant was pulled from each plot and Root Galling RGI was performed along with *Verticillium* and *Fusarium* Assessments. RGI was assessed on a scale of 1 to 5 as indicated in Table 3:

Table 3. Assessment of RGI in plastic tunnel experiment.

Galling Index	№ of Galls on Root canopy	Diameter of Galls (mm)
1	0-Sparse	$\leq$1
2	Sparse Galls	1-2
3	Non- Coalescent Galls	2-3
4	Numerous Galls	3-4
5	Extremely Abundant Galls	>4

The Baermann Funnel technique was used as a nematode extraction and larvae separation technique. Mounts for nematode identification were prepared.

Results and discussion

The soil was clayey loam, slightly alkaline (pH of 7.3), non saline, calcareous ($CaCO_3$) with sufficient levels of micro and macronutrients. During the season, results and severity of infections were estimated from isolations as shown in Table 4.

Table 4. Degree of infection in different treatments.

Treatment No.	Root Galling Index	Nematode	Fusarium	Verticillium
1	0.5	+	-	+
2	1.5	++	+	+
3	2	+++	++	++
4	1.2	++	++	++
5	4.5	+++++	++++	++++

+ : Low Concentration
++ : Medium Concentration
+++ : High Concentration
++++ : Very High Concentration
+++++ : Extremely High Concentration

Plants amended with NH_4OH showed an abundant growth as compared to the control treatment; this could be due to the higher N supply. NH_4OH also led to the reduction of root knot galling of tomato plants and *Fusarium* and *Verticillium* infections (Table 4, and Figures 1 and 2).

Results show that ammonium hydroxide at a rate of 100 ml NH_4OH/m^2 almost doubled the yield of tomato (Figure 1) and reduced RGI from a rate of 4.5 to 0.5 (Figure 2).

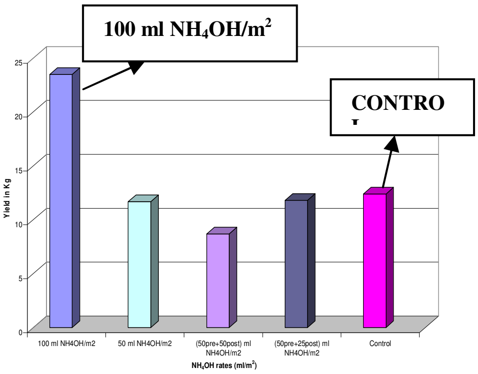

Figure 1. Effect of NH_4OH concentrations on yield of tomato

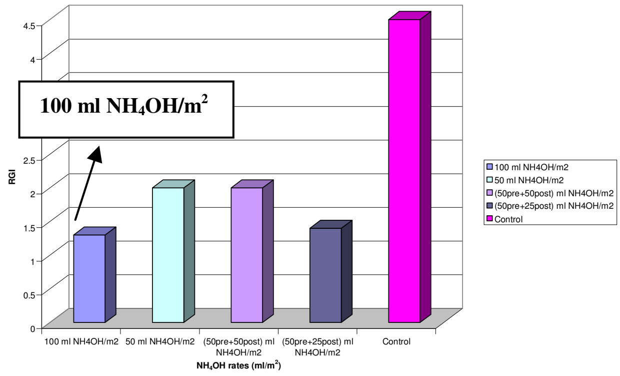

Figure 2. Effect of NH_4OH concentrations on RGI of tomato

The pre-planting application of NH_4OH was found to be more effective than the post-planting application of NH_4OH. Actually, it is recommended to only apply NH_4OH Pre-planting because of its toxicity effects on the plant if applied during the growing season. The results were obtained when NH_4OH was applied pre-planting at a rate of 100 ml/m^2

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Genesis of calcic concentrations in Arguidolls of the Argentinian Pampa

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Abstract
The characteristic morphology of pedogenic calcic accumulations in the Argentinian Arguidolls were studied in the southern east part of the Buenos Aires province; their distribution down the soil profile and mechanism of their formation were examined. In the monolithic samples the carbonate collomorphic (cryptocrystallic) films and carbonate tubes were examined by scanning electronic microscope observations. The origin of these carbonate accumulations is chemical. Spheroid gypsum concentrations (framboids) located on the boundary between the A humus and Bt1 illuvial horizons are most likely biogenic. Two ways of formation for those spheroid gypsum concentrations are considered: accumulation of crystal "crusts" around less soluble mineral (probably calcite) by spherical cyanobacterial colonies or the spherical form of concentrations has been inherited from framboid pyrite concentrations from sea sediment which decayed by sulfate-reducing bacteria. It is suggested that gypsum cyanobacterial concentrations have seasonal dynamics of formation in the soil profile. They are formed in the soil profile only during dry seasons whereas in humid seasons they are dissolved and disappear from the profile.

Key Words
Gypsum spherolite, framboid, cianobacteria, endolithic colonies

Introduction
Modern Arguidolls of Argentinian Pampa are forming on paleosols and marine, eolian, fluvial and paludal sediments. The complex history of soil formation and landscape evolution has been described in papers by Zarate (2009) and Kemp (2006): 128 thousand years ago marine sediment, usually carbonate, deposited on fine paludal silts, then on some locations these marine sediment were overlaid by fine silty deposits of fluvial/paludal genesis (before 23 thousand years ago), after that the eolian loess deposits were formed approximately 10 thousand years ago. Sometimes pedo- and lithogenesis were simultaneous. So, the parent material for modern surface soils is free carbonate loess, but underlaying layers influence soil formation.
In the Argentinian Arguidolls the secondary carbonates concentrations (hypocoatings and nodules) and/or inclusions of lithogenic limestones (Borrelli *et al*. 2009) have been described. Besides, in coastal soils biogenic calcite formation through calcium oxalate has been shown. Morphology of biogenic calcite varies from needles and tubules crystals similar to fungi hyphas to traditional rounded and micrite forms (Verrecchia *et al* 1993). In these soils biogenic transformation of pyrite (FeS_2) by sulfate-reducing bacteria occurs (Osterrieth 2005). The morphology of these concentrations is special – rounded (framboid) accumulations called after 'la framboise' in French.

Objects and methods
Profile of typical Mollisol formed on loess underlying by paleopedolith (tosca) on seaside in south-east part of Buenos-Aires province, Argentina, between 37° / 38°40' S and 59° / 57°10' E. This area is subtropical preria and nowadays use as agriculture lands.
Sampling was in three horizons: border A and Bt1, Bt2 and 2Ck – sample 1, 2 и 3, accordingly.
The sample 1 - very friable, porous, dark-grey with whitish spots and fibers;
The sample 2 – light-pale, loess with vertical fractures and root/mesofaune holes;
The sample 3 –carbonate crust ("*tosca*"), grayish-white, very dense, derives on different size carbonate concentrations.
Monolith air-dried sample were studied under binocular and scanning electron microscope. We used scanning electron microscope Jeol model JSM-6380LA. Elemental analysis was conducted by X-Ray microanalysis EDS JED-2300.

Results
The sample 1, humus black horizon contains bright-white thin coating; a reaction with 10% HCl is very local, it is possible to locate it only under binocular. Already at hundred-fold magnification the white "thin coating" is

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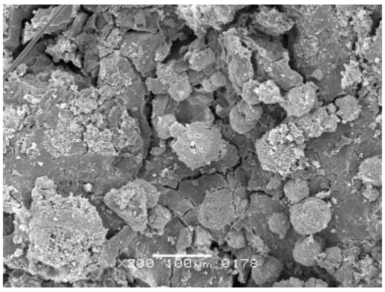
localised in spheroliths (framboids) from 10 to 100 microns in diameter formed by perfect crystals (Figure 1, a). EDS data has shown that it is gypsum crystals, characteristic external shape also testifies to it. Sometimes these framboids are connected in chains (Figure 1, b) and have small hollows on poles. In separate framboids iron is presence (according to EDS-SPECTRA). Gypsum spheroids rise slightly above general surface of the sample. Between them the thin collomorphic (cryptocrystallic) films of calcite on alumosilicate (Figure 2, a) have been observed. Such films have been repeatedly noted by us in the soils of different regions of the world characterized by a contrast water regime with strongly pronounced period(s) of humidifying and drying (Kuznetsova and Khokhlova 2009). On the sample surface the threads and congestions of cyanobacteria are noted. On individual cyanobacterium small gypsum crystals are visible (Figure 2, b).

The sample 2. It reacts with 10% HCl very poorly, locally. Thin discontinuous carbonate tubules which have been found out under binocular, are very fragile and easily disintegrated. Carbonate concentration under a scanning electronic microscope is not revealed. Basically it is slightly carbonate matrix consisting of a mixture of alumosilicate grains, "pure" and covered by thin carbonate film (Figure 3, a). Cyanobacteria are not revealed, there are separate hyphas only. The sample 3. The most carbonate sample reacts with 10% HCl violently. The matrix is a mechanical mixture of alumosilicate grains (almost without films) and porous, imperfect calcite crystals (Figure 3, b). In small holes calcite transforms to a collomorphic film which smooths out a relief, but chaotically scattered crystals and druses prevail.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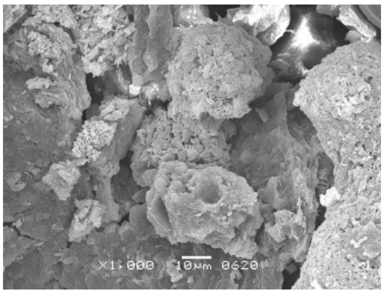
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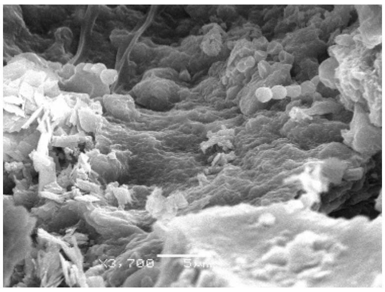
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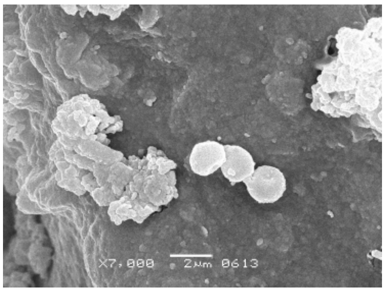
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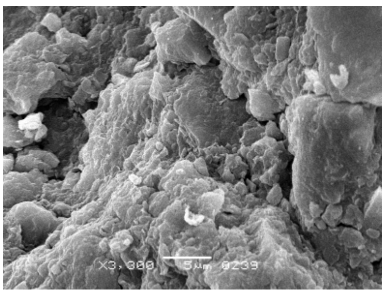
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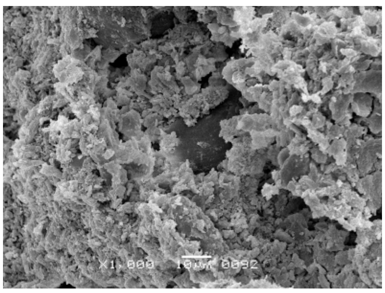
Figure 3, b

Discussion

According to obtained data on the border of humus A and Bt1 horizons the conditions for a life of cianobacteria which promote loss of a crystal deposit – biogenic soil concentrations are created. Formation of lime mats by direct participation of cyanobacteria since the Pre-Cambrian is frequently described in the scientific literature (Zavarzin 2003). Besides, spherical mats – oncoliths - are known. In them lime layers settle down not linearly, but are rounded.

In modern soils the endolithic cyanobacteria are described and found in soil gypsum crust of various deserts of the world (Dong *et al* 2007, Garcia-Pichel *et al* 2001). Similar cyanobacteria communities form laminae inside the gypsum horizon. Depth of colonies penetration depends on a gypsum structure that finally from possibility of water, oxygen and light penetration: in more porous samples cyanobacterial colonies permeate more deeply. It is thus underlined that cyanobacteria being extreme species can live in light and minimum oxygen conditions. Thus, cyanobacteria communities can support the biodiversity as endolithic species (Osterrieth 2005).

In the sample 1 we observed the formation of concentrations like oncolithes, not calcitic, but gypsum. Such structures in soil have not been described earlier, but their existence is quite possible. We will compare the following data for cyanobacteria concentrations on various substrata, both in modelling experiments, and in natural conditions which are indentified in the scientific literature:

- Sedimentation by individual cyanobacterium cells round itself by calcite crystals ($CaCO_3$), trona (Na_3H (CO_3) (H_2O)), halite (NaCl) (Howell *et al* 2005, Mikhodyuk *et al* 2008);
- Formation of roundish and layered calcite mats by cyanobacteria in natural conditions (Zavarzin 2003);
- Formation of stalactite-like structures from halite and gypsum and having of a layered structure:, around cyanobacteria colonies with gypsum, further a mixture of gypsum and halite and then pure halite (Braithwaite and Whitton 1987);
- High-grade functioning (with a closed cycle) cyanobacteria colonies in gypsum crust (Dong *et al* 2007, Garcia-Pichel *et al* 2001, Mikhodyuk *et al* 2008);
- Existence in Argentinian Arguidolls of biogenic concentrations/framboids as products of pyrite and calcite decomposition (Osterrieth 1992, 2005).

According to these data, gypsum concentrations on the bottom boundary of humus horizon have a biogenic origin. Two ways of their formation are possible.
1. Cyanobacteria colonies having the spherical form build up crystal crusts round themselves. Possibly, they occur at the change of a wet season to dry season when the concentration of soil solutions sharply rises. By analogy with a study by Braithwaite and Whitton (1987) we assume that less soluble mineral is situated closer to central part of these spherolites. Probably, this mineral is calcite.
2. The spherical form of concentrations has been inherited from framboid pyrite concentrations (Osterrieth 2005), because according to EDS-spectra iron is observed. In this case, pyrite transformation occurs step-by-step, through a number of other minerals. Calcium for formation of these gypsum framboids undertakes from an underlaying calcareous horizon (2Ck), or arrives with an atmospheric precipitation or plant waste. Sulphur appears as a pyrite decomposition product which has been described in these soils. Studying the mechanism of such transformations requires additional mineralogical modelling experiments.
In one case or another, gypsum cianobacterial spherolith is concentric with short-term life, their formation and functioning in soil is possible only during dry seasons. Most likely, during a season of rains similar biogenic concentrations we will not find out in the soil profile studied. Probably, both ways of biogenic genesis of soil concentrations studied take place and are realized on the bottom border humus horizon of Argentinian Arguidolls.

The sample 2: carbonates uplifting from underlaying horizon, only along thin tubes. Formation of macroconcentrations does not occur. Possibly, it is connected with sharp distinction in a structure of porous loess and well-packed underlaying "*tosca*" which is poorly dissolved, calcite uplifting occurs only along thin tubes in loess by roots. Thin discontinuous carbonate tubes are formed in such way. Collomorphic films are resulted from calcite precipitation during water regime changing from saturated colloidal solutions (Kuznetsova and Khokhlova 2009). In the studied soil this process occurs on phase interfaces at a microlevel when solutions cover particles as thin film, and from the observation of the concentrations (collomorpic films) obtained is also possible at micro - or even submicrolevels.

In sample 3 there is a fast recrystallization of limestone from strongly saturated solutions, the most part of the material does not move but is precipitated *in situ*. Therefore, there are no concentrations with perfect crystals and their formation is possible only in quiet conditions and from solutions with normal concentrations. The considerable admixture of alumosilicate grains comes, probably, as a reflexion of simultaneous sedimentation of limestone and loess.

Conclusion

In the studied Argentinian Argiudolls the calcium concentrations of different genesis are revealed: on the boundary of humus horizon and loess deposits cyanobacterial gypsum concentrations of a biogenic origin are described; chemogenic carbonate collomorphic films on a surface of alumosilicate matrix were observed in all samples, and, besides the carbonate tubes in loess and re-crystalled limestone in the 2Ck horizon have chemical genesis. Two modes of formation for those spheroid gypsum concentrations are considered: accumulation of crystal "crusts" around less soluble minerals (it is probably calcite) by spherical cyanobacterial colonies or the spherical has been inherited from framboid pyrite concentrations from sea sediment which were decayed by sulfate-reducing bacteria. It is likely that gypsum cyanobacterial concentrations have seasonal dynamics of formation and occurrence in the soil profile studied. They are formed and exist in the soil profile during dry seasons and in humid seasons they are dissolved and disappear from the profile.

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Importance of subsurface soil pockets for plant growth in a karst environment

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Abstract
Northern Yucatan has generally shallow soils (< 30 cm depth) underlain by limestone, and an aquifer at several meters depth. Pockets of soil have accumulated within the limestone bedrock as a consequence of rock dissolution and illuviation of finer materials from topsoil. These soil pockets are thought to be additional sources of water and nutrients for plants but their abundance and properties have been poorly studied. This study was conducted in a limestone quarry, where the aquifer is at 9 m, to determine the abundance and distribution of soil pockets and to compare their physical properties with those of the topsoil. Soil pockets represented about 12 % of area of the vadose zone, whereas topsoil occupies only 3.3%. The volume of the soil contained in soil pockets was twice as much as the volume occupied by topsoil. Deeper and finer roots were regularly associated with soil pockets. Soil pockets had 3 times more clay and 10% less porosity compared with topsoil. Available water was similar in topsoil and soil pockets because field capacity and permanent wilting points were higher in soil pockets. Soil pockets are more abundant than previously thought and have different properties than topsoil.

Key Words
Northern Yucatan, leptosols, shallow soils, rendzinas, soil accumulations, limestone bedrock

Introduction
Karst areas constitute about 10 % of land surface of the world (Ford and Williams, 1989). They are terrains with distinctive characteristics of relief and drainage formed over any kind of soluble rocks such as limestones, dolomites and evaporites (Jennings, 1985). Karst in Yucatan, Mexico, developed on limestone, has no surface streams, and shows different developmental stages (Finch, 1965). In Northern Yucatan, where the youngest stage is present, the vadose zone is composed of a shallow layer of soil, the *laja*, a consolidated rock exposed or immediately underlying soils (Duch, 1988; Espinosa *et al*., 1998; Perry *et al*., 1989); the *sascab*, a subsurface non-indurated softer limestone with high porosity (Duch, 1988; Espinosa *et al*., 1998); and the *coquina*, a highly fossiliferous rock with high void percentage, found above the water table (Espinosa *et al*., 1998). Within the limestone matrix there is a number of dissolution cavities ranging in size from pores (< 0.1 to 1000 mm) to caves (big enough for a person to get in), including soil pockets (cavities filled with soil). Soil pockets start as empty cavities formed by the dissolution of the matrix of the limestone and are filled with soil material afterwards. These soil pockets are thought to be important as additional sources of water and nutrients for plants, but their abundance and properties have been poorly studied. The aim of this study was to investigate the abundance, distribution and physical properties of soil pockets in northern Yucatan, Mexico. Properties of soil pockets were compared with those of the topsoil to discuss their importance for plant growth.

Methods
Study area
The study site was a limestone quarry located approximately 10 km south of Merida city (20°54'18.86"N and 89°37'49.64"W), in the state of Yucatan, Mexico. Vegetation was a 15-year-old deciduous forest. The quarry is currently mined for gravel, lime, and cement leading to daily exposure of fresh walls. Vegetation and soil are removed before blasting the rock. One freshly exposed wall was observed and sampled every month from June 2007 to May 2008 (except for April).

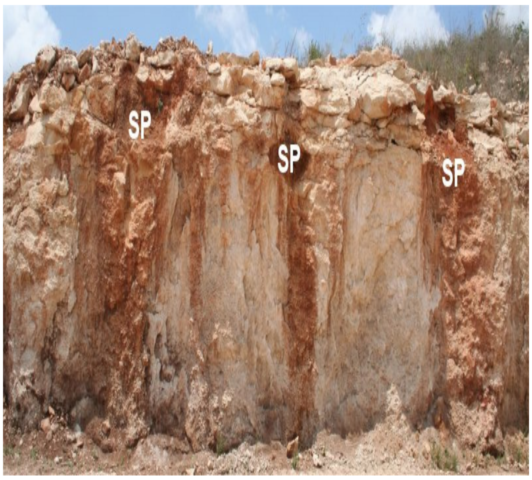
Soil pockets distribution
Ground surveys were conducted with a SIR-3000 system portable Ground Penetrating Radar (GPR) unit (Geophysical Survey Systems, Inc. Salem, NH) with a 400 MHz antenna. A 190-m traverse line was established along a road adjacent to the quarry on the land surface. Soil was not removed. Position markers were inserted into the radar record as landscape features changed. The antenna was pulled manually. Surveys were conducted in May, the end of the dry season, to minimize attenuation of the signal due to a high water content of the soil and rocks.

Abundance of soil pockets
For area assessment of soil pockets, digital photographs of recently exposed walls were taken after blasted rock was removed. A photomosaic was created by joining the individual pictures with the program Photostich v3.1 (Canon, USA). On the photomosaic, empty cavities and soil pockets were drawn using the program CorelDraw v11 (Corel Corporation, USA). A different color was assigned for each different feature (1=rock matrix, 2=cavities and, 3=soil pockets). 24 bits Bitmaps of the photomosaics were imported into IDRISI32 (Clark Labs, USA) where they were cut in three sections; each representing one rock layer. The area of the karst features was calculated by using the tabular option of the module AREA.

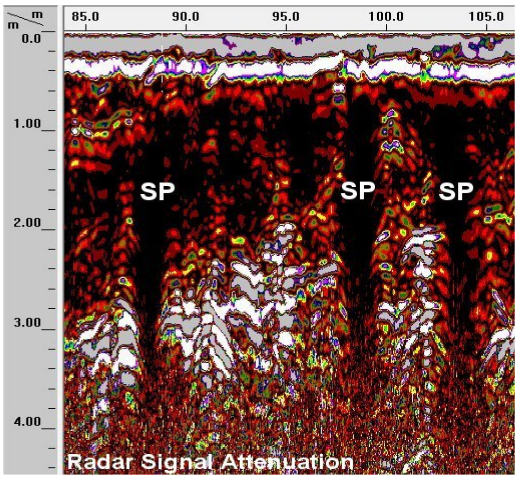
Root distribution
For assessment of root distribution, one 40 m width X 7.5 m height wall was sampled monthly. Walls were gridded into 1.25-m X 1-m sections. The first 1.25 m of the upper rock layer was not sampled to avoid most shrub and herbaceous roots. In every section root tips > 1 mm in diameter were counted. The root percentage was calculated for the rock matrix, soil pockets and empty cavities.

Soil analyses
Soil physical properties were analyzed for samples from three representative soil profiles and six soil pockets. Properties analyzed were particle and bulk density, particle-size distribution, porosity, and volumetric water contents at field capacity (FC) and permanent wilting point (PWP). Particle density was analyzed with a gas pycnometer (Accupyc 1330; Micromeretics Instrument Corporation, Georgia, USA). Bulk density was measured using the core method (Blake and Hartge, 1986). Particle-size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Porosity was calculated as 1- (bulk density / particle density) X 100. Water contents at field capacity and permanent wilting point were obtained using the pressure plate extractor method (Dane and Hopmans, 2002).

Results
A great number of soil pockets of different sizes and shapes were observed in the field. Large soil pockets, similar to the ones observed in Figure 1a, were detected with GPR (Figure 1b)**.** The large number of potential soil pockets observed along the GPR traverse line suggests that, at least in some areas, they may be a more common occurrence in this landscape than originally thought. Most of these pockets are located in the middle part of the vadose zone where the limestone bedrock is softer.



(a)



(b)

Figure 1. Soil pockets a) soil pockets in the field, b) soil pockets as recorded by using a GPR

Soil pockets represented about 12 % of area of the vadose zone (9m), whereas topsoil only 3.3% (Figure 2). This proportion is relatively constant during the year although areas with no soil pockets and areas with more than 12 % were also observed.

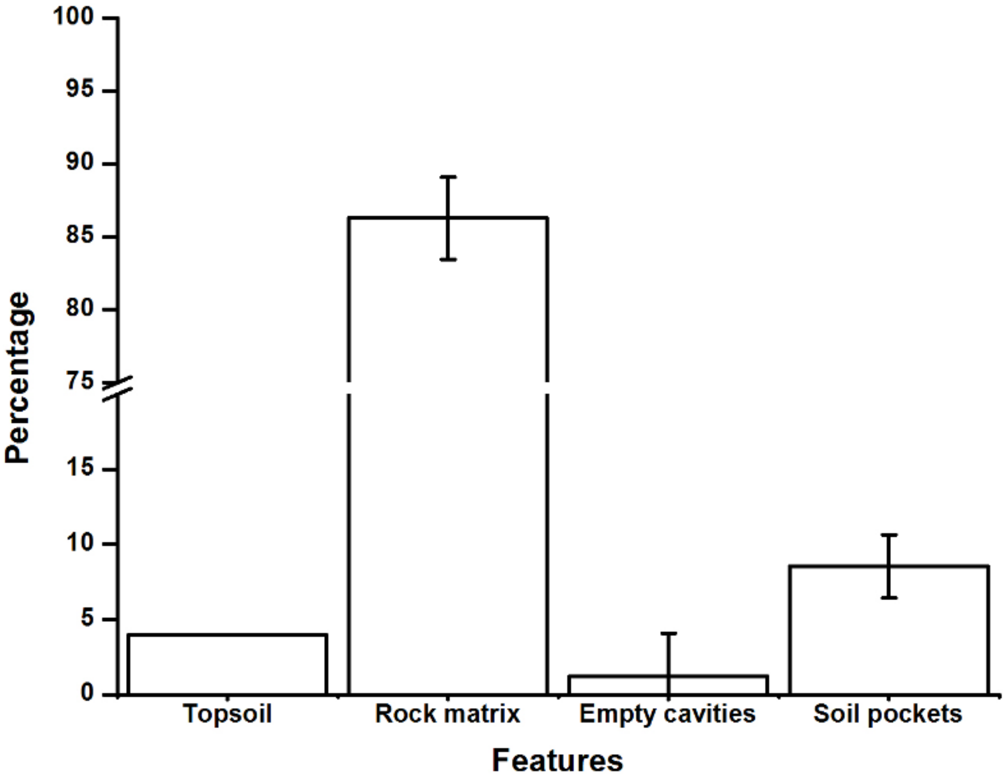


Figure 2. Soil pocket abundance in the vadose zone of northern Yucatan

Although most of the roots are confined to the topsoil (data not shown), there are a large number of roots growing in the rest of the vadose zone (Figure 3). Regardless of their location, soil pockets always contained roots. Finer roots were more abundant than coarse roots in these features. Deeper roots were always associated with soil pockets.

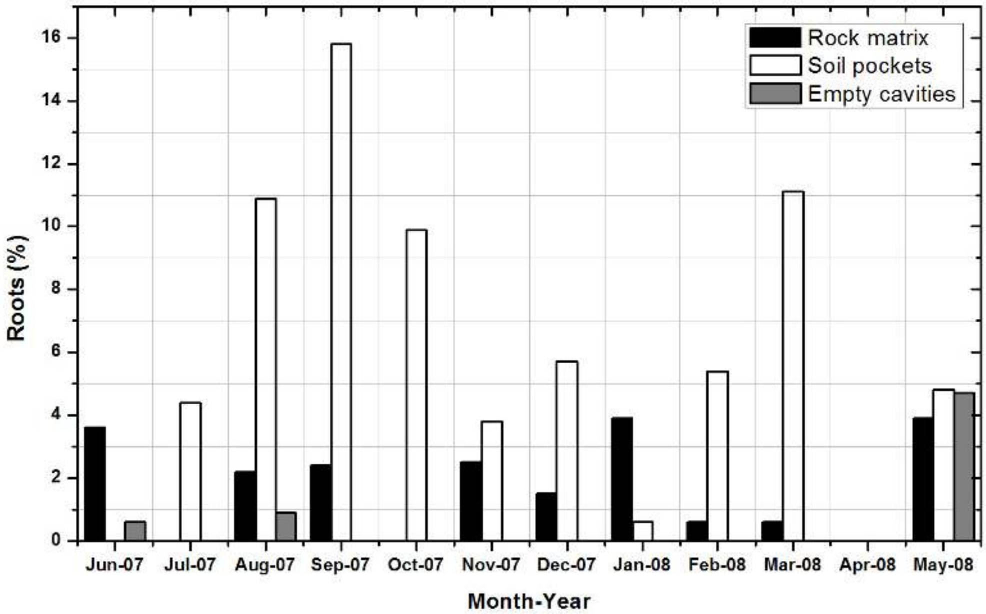


Figure 3. Root abundance in the subsurface karst features of northern Yucatan.

Soil pockets had 3 times more clay and 10% less porosity than topsoil (Table 1). Available water was similar in both topsoil and soil pockets but field capacity and permanent wilting points were higher in soil pockets. Bulk density in topsoil is lower than that of the soil pockets due to the high density of roots in the shallow soils.

Table 1. Selected physical properties of topsoil and soil from pockets.

Sample depth (cm)	Particle density (g cm^{-3})	Bulk density (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	Porosity (%)	FC (%)	PWP (%)	AW (%)
Topsoil (n=3)									
0-30	2.56 (0.015)	0.815 (0.015)	66.5 (4.2)	16.3 (6.15)	17.2 (1.6)	68	25.1 (1.35)	13.2 (2.0)	11.9
Soil pockets (n=6)									
30-300	2.58 (0.001)	1.09 (0.045)	21.5 (0.6)	12 (0.6)	66.5 (0.85)	59	32.1 (2.0)	21.0 (1.3)	11.1

FC= volumetric field capacity; PWP= volumetric permanent wilting point; AW= available water. Numbers on parentheses are standard deviations.

Soil pockets occupy more volume than topsoil in the vadose zone of northern Yucatan. Consequently, there is more water held in soil pockets than topsoil (Table 2).

Table 2. Volume occupied in the field vs Available Water (AW) of topsoil and soil pockets.

	Volume (m^3 ha^{-1})	AW (m^3 m^{-3})	AW (m^3 ha^{-1})
Topsoil 0-30 cm	3000	97.2	291,600
Soil pockets 30-300 cm	6640	121.0	803,440

Conclusions

Abundance of soil pockets is greater than previously thought; they occupy a greater volume than topsoil. Soil pockets represent pathways for roots, places for avoiding shallow rooted competitors, and additional sources of water, especially during the dry season when water at topsoil is limiting. Water is better preserved in soil pockets because they are not exposed to solar radiation. Properties of soil pockets are different from those of topsoil. Clay content in soil pockets supports the idea that empty cavities are filled by illuviation of fine soil materials from topsoil. Thus, roots growing in soil pockets could have different growth adaptations compared with those roots growing in topsoil.

Acknowledgments

This project was supported by UCMEXUS, the National Science Foundation (DEB 0615427, EF0410408, and CRR-0120778), and the UCR Center for Conservation Biology.

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The exokarstic soil record of past environmental changes: Regional expressions

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Abstract
We intend to promote using microfacies analysis how the Quaternary deposits filling karstic cavities that are part of galleries connected by vertical chimneys to the outside surface soils provide an original view on the reactivity of limestone landscapes to short-term environmental changes. Our purpose is illustrated by the early to middle Pleistocene sequences from the Sierra de Atapuerca (Burgos, Spain) and the late-Pleistocene/Holocene sequence of Song Terus (Gunung Sewu hills, Java Island). The micromorphological study and complementary analytical data have allowed subdividing the pedo-sedimentary facies into six types in terms of accumulation and pedogenic processes: (F1) Weakly pedogenised sedimentary facies; (F2) Weakly pedogenised pedo-sedimentary facies; (F3) Excremental pedogenic facies; (F4) Dark organic-rich facies; (F5) Calcitic facies; (F6) Firing facies. They are shown to reflect the range of short-term events that might have severely degraded the soils forming on the limestone landscapes along the course of the Quaternary period in response to various initiating factors, i.e. exceptional abrupt climate changes, wild-fires, volcanic eruptions or cosmic impacts. The rapid fossilisation and the negligible anthropogenic bias explain the excellent preservation of the pedo-sedimentary records in the subsurface karstic galleries. Further study should help to better understand the effects of these ecological crisis on human and animal communities that were occupying in the past the limestone landscapes.

Key Words
Facies, pedo-sediments, surface, fire, events

Introduction
The ongoing studies of deposits that accumulated through the Quaternary period at the foot of rockshelters and karstic cavities of limestone landscapes continue to provide valuable paleoenvironmental data on the past dynamics of terrestrial ecosystems after decades of research (Goldberg and Woodward 2001). The complex spatial variability of facies changes due to local factors and interactions of past animals and humans, which occasionally occupied these natural habitations, on sedimentary processes and pedogenesis is now well controlled by appropriated methodologies (Courty, 2001). Sharp stratigraphic discontinuities due to intensified detritism from the walls and enhanced pedogenesis at the soil surface have been shown to reflect sudden ecological stress generated at a micro-regional level by abrupt climate changes, i.e. .the Dansgaard-Oeschger cycles, the Heinrich events or the severe cooling of the Younger Dyras and 8.2 kyr BP events (Courty Vallverdu, 2001) from caves of Mediterranean regions. At the la Ferrasie rockshelter, a series of dark organic facies that are interbedded within the frost-produced sedimentary deposits have been interpreted to express episodes of soil formation during the Dansgaard/Oeschger climatic cycles of MIS 3 (Bertran *et al*., 2008). Humus development was thus suggested to have occurred in situ from accumulation of organic matter brought into the cavity by wind, water flows, animals, algae, lichens, mosses, thus producing specific humic compounds associated with weak horizonation in contrast to those in ‘normal’ soils.
Here, we further investigate the originality of the cave soil-like deposits in comparison to soils of the outside surroundings. Our aim is to establish correlation between the range of pedo-sedimentary processes involved in their formation with major changes in the soils formed at the same time on the limestone landscapes in response to climate variability, wildfires, volcanism, or cosmic events.

Materials and methods
Our study is illustrated by two karstic cavities that are part of long gallery network connected to the outside surface by vertical chimneys. The Sierra de Atapuerca (Burgos, Spain) is famous for its oldest direct evidence of hominids in west Europe, ca 1.2 Ma (Carbonell *et al*., 2008). The karstic complex comprises three levels of subhorizontal galleries. The present-day altitudinal continental climate is marked by Atlantic influences. The highly eroded soil cover consisting of Camborthids on reddish decalcified colluvial loam lies abruptly on the unweathered Mesozoic limestone formed of bioclastic grainstone. The deposits represent five distinct phases of filling well dated by radiometric techniques and paleomagnetism from the early Pleistocene to the late Pleistocene (Carbonell *et al*., 2008). They yielded a profusion of archaeological layers with well preserved

assemblage of lithic, bones and human remains that have been for long extensively excavated (Carbonell *et al.*, 1995).

The cave of Song Terus, located in the Gunung Sewu hills (Java Island) is part of a typical karstic landscape in an intertropical environment. The karst started to form during the Early Pleistocene from the Miocene reef coarse bioclastic limestone The highly dissected cone-shaped hills with levels of cavities result from the interaction of the constant regional uplifting due to tectonic activity and intense physical-chemical erosion due to high rainfall (Quinif, Dupuis, 1985). The sequence comprises more than 10 m thick of fluviatile accumulation, overlaid by 5m thick of terra rossa deposits with 3 archaeological layers: at the bottom the Middle Pleistocene Terus layer, the late Pleistocene Tabuhan layers and the Keplek Holocene sequence (in Gallet 2004; Figure 1).
The vertical sequence of the pedo-sedimentary facies and their spatial variability were studied from the sections exposed by the excavation. Continuous columns of undisturbed blocks were collected for thin section preparation. Bulk samples were collected from the distinctive strata, including their lateral variations, for compositional analyses of the coarse and fine components by X-ray diffraction, Raman micro-spectrometry and isotope analysis.

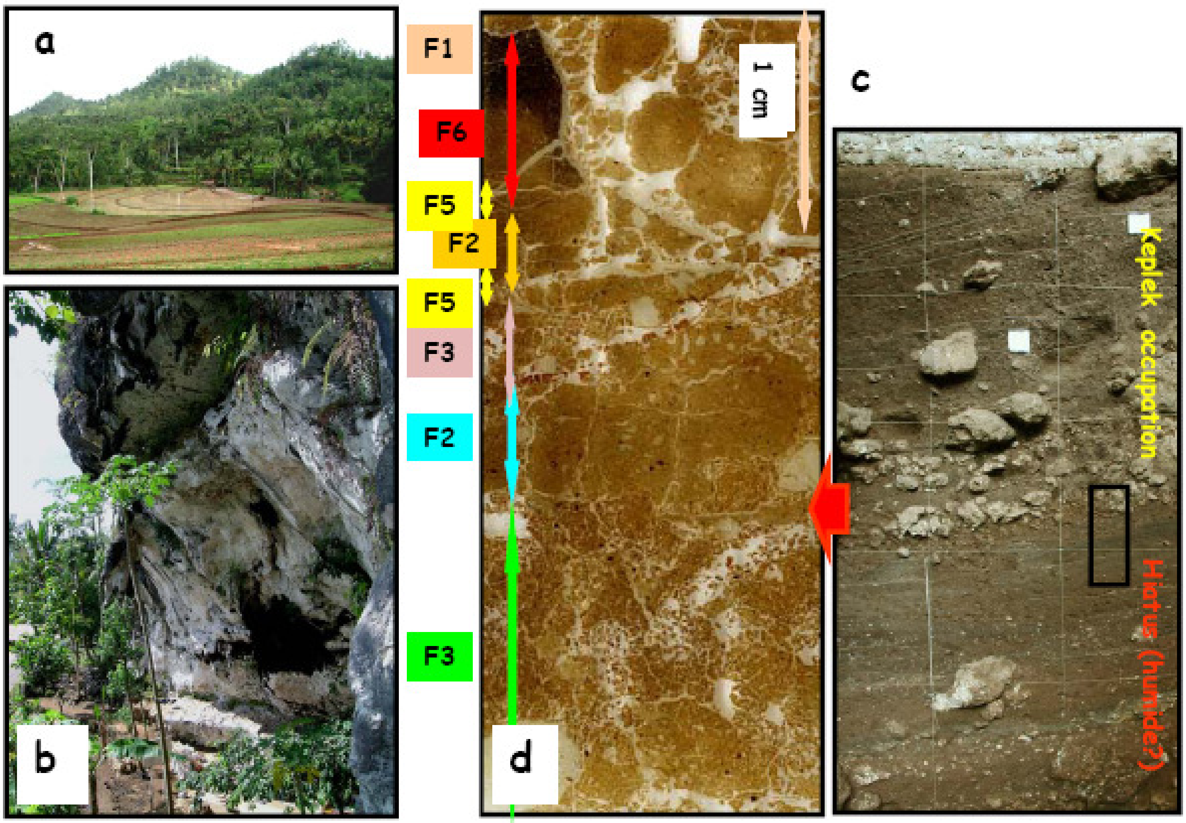

Figure 1. (a) The Gunung Sewu hills and (b) entry of Song Terus cave. (c) Stratigraphy of the upper Holocene layers (Keplek occupation deposits) and the late Pleistocene sequence (no occupation). (d) Photo-scan from thin section showing successive events at the terminal Pleistocene (possibly record of the Younger Dryas) showing the distinctive pedo-sedimentary facies (cf. the text for the description and paleoenvironmental significance) with sharp contact.

Results and discussion

The occurrence of pedological features and their degree of preservation allows classifying the pedo-sedimentary facies into five main categories. (F1) Weakly pedogenised sedimentary facies: massive or laminated, with common sedimentary features, they do not show a distinctive micro-aggregated structure of biogenic origin; pedorelicts are rare; when present limestone fragments have a sharp contact with the decalcified host matrix. Sediments can be of local provenance and/or integrate allochtonous components.
These characteristics indicate rapid transfer into the cavities by mass flow of relictual soils covering a highly eroded limestone landscape with a scarce vegetation cover. In the case of allochtonous sediments, i.e. massive tephra at Song Terus, the lack of weathering indicates an arrival in the cavity just following their deposition at the outside soil surface. (F2) Weakly pedogenised pedo-sedimentary facies: generally massive with rare

sedimentary features, they display abundant pedo-relicts largely dominated by textural features and occasional excremental assemblage; the rare limestone fragments have a sharp contact with the decalcified host matrix. These characteristics indicate rapid transfer into the cavities by mass flow of well developed soils that were extensively covering the limestone landscape; lack of weathered limestone fragments shows that the buried karstic galleries were not directly exposed to deeply penetrating plant roots.

(F3) Excremental pedogenic facies: they present a heterogeneous assemblage formed by the dense to loose packing of disturbed biogenic aggregates and subangular aggregates and rare textural features; the common limestone fragments are fresh to weakly decalcified, often associated to thin calcitic coatings.

These characteristics indicate a formation by disaggregation of the cavity wall that was densely colonized by plant roots issued from the vegetation covering the limestone landscape. The heterogeneity of the assemblage reflects interaction of physical and biochemical processes on the production of aggregates, more likely in response to periodical fluctuations of rainfall.

(F4) Dark organic-rich facies: They share in common a massive to open micro-aggregated structure, the abundance of humified fragments in the decalcified fine mass together with common charred remains, the occurrence of weakly to strongly weathered calcitic features showing amorphous coatings and hypocoatings, and occasionally dusty, finely laminated textural features.

This complex assemblage expresses the succession of two pedogenic phases: (1) the formation of speleothems on the cavity walls and on the ground by dripping of carbonate-saturated water that was slowly percolating through the calcareous soils covering the limestone landscape; (2) the degradation of the speleothems caused by dripping of waters that were enriched in organic acids following their percolation through a thick humic layer. The shift between the two phases suggests a change from a marked seasonal contrast to a globally pronounced humidity with the formation of poorly drained soils in the limestone landscape. The high char content indicates periodical wildfires, possibly during severe drought, that were greatly facilitated by the thick accumulation of biomass in the surrounding landscape. The long maintained humidity during phase 2 appears to have favoured the invasion of the karstic cavities by plant roots and their active corrosion by the organic substances. The record of distinctive wildfire events that are associated to the input at the soil surface of exogenic debris is represented by a distinctive signal in the two cavities.

F4 displays a wide range of sub-facies that expresses the spatial variability of local conditions, i.e. phosphatised organic facies due to high production of phosphate-rich organic substances by cryptogamic vegetation, or finely laminated organic-rich facies resulting from gentle runoff in the cavity at places of intense dripping and pound formation.

(F5) Calcitic facies: They range from thin laminated festoon-like calcitic bands that develop within thin fissures of F4 facies to thick, polyphased laminated calcification, i.e. the speleothems. They result from dripping of carbonate-saturated water with low suspended charge. The low amount of detrital inclusions or pedo-relicts implies that their development was contemporary with the formation of thick calcareous soils on the limestone landscapes and sufficient rainfall for generating a positive hydric balance.

Their thickness and complexity reflects the duration of the accretionary period, and subtle changes in the soil cover in response to climate variability.

(F6) Firing facies that include two sub-types: (F6a) the thick homogenous ashy facies formed of loosely packed phytoliths finely mixed with excremental aggregates (i.e. Song Terus) and (F6b) the dark brown carbonaceous thin facies formed of clay-rich amorphous organic matter with abundant charred remains (Atapuerca). These characteristics reflect sudden firing of considerable amount of biomass from the outside soils rapidly followed by their transportation to the cavities due to subsequent high rainfall. The incorporation of surface horizons indicates that the intense firing of the vegetation and of the humus layers had also severely deteriorated the soil cover.

Figure 1 illustrates a typical series of short-term events from the deposits of Song Terus cave. The unique dark firing facies (F6 on Fig. 1d) occurring just below the Pleistocene/Holocene transition is tentatively interpreted to represent exceptional firing liked to the Younger Dryas boundary events (Kennet *et al*., 2008). This correlation is based on the occurrence of high amount of mineral and organic markers that we suggest to be typical of cosmic airbursts (Courty, Fedoroff, this volume).

Conclusions and perspectives

The study of the Quaternary sequences from these two subsurface karstic galleries provide a challenging perspective in comparison to the classical view that previously concluded to the limited paleoenvironmental interest of exokarstic deposits. The proposed inventory of distinctive pedo-sedimentary facies appears to reflect the range of ecological crises that might have severely affected limestone landscapes in response to various initiating factors. The short-term pedogenic events that we have identified seem to contrast the well established

correlation between long-term soil development during globally stable interglacial periods and formation of speleothems in the underground karst. In fact, the two examples presented show that the record of peculiar situations affecting the outside soils simply benefitted from rapid fossilisation in the subsurface karstic galleries, whereas taphonomic processes, erosion, or human activities might have biased or erased their fingerprints in shelters or wider cavities. A refined timing of the pedo-sedimentary succession will help to better understand how limestone landscapes reacted to the natural stress exerted. Refined absolute dating is also critical to establish regional and long distance correlation, specifically with the distinctive signal of short-term events that is now well extracted from high resolution records on the basis of various proxies.
The future, an increasing research effort on the Quaternary filling of subsurface karstic galleries should greatly help to improve our knowledge on the effects of natural hazards on the soil cover on limestone landscapes for key periods of rapid changes and on their regional expressions. The close collaboration with archaeologists and related paleoenvironmental disciplines should greatly contribute to control the bias exerted on the pedo-sedimentary record of the natural events by anthropogenic factors. In addition, the integration of cultural perspectives with the pedo-sedimentary data would help to debate the consequences of the ecological crises on past human and animal communities.

Acknowledgments
We are grateful to Professor Hary Truman Simanjutak and Professor François Semah for providing use access to the cave of Song Terus. We thank all the members of the French-Indonesian team for their kind assistance. The support of the Atapuerca foundation is greatly acknowledged. We are greatly indebted to all our friends and colleagues for their full support.

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Thermal characterization of lime stabilized soils

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Abstract
In this paper, the time-dependent changes induced in the thermal properties of lime treated bentonite comprised mainly of montmorillonite mineral and a tropical lateritic soil rich in iron oxide were investigated. The thermal gravimetric analysis (TGA) indicated that evaporation of the adsorbed surface water was the main reason responsible for the weight losses observed in the lower temperature regions. Nevertheless, in 8 months cured bentontie samples, a new drop at around 285ºC due to the evaporation of moisture encapsulated into the reaction products was evident. Also, it was found that in laterite clay mix designs, lime treatment had a marginal impact on the thermal properties of the soil. From geotechnical point of view, the stabilization technique was far more effective in improving the strength properties of bentonite soil over the 8 months curing period.

Key Words
Bentonite, lateritic soil, lime stabilization, thermal properties

Introduction
Thermal analysis involves a dynamic phenomenological approach to the study of soils by observing its response to a change in temperature. The results for this type of analysis can be obtained in three different ways, i.e., thermal gravimetric analysis (TGA), differential thermal analysis (DTA), and derivative thermal gravimetric (DTG) analysis. For clays, endothermic reactions involve desorption of surface H_2O, dehydration at low temperatures, dehydroxylation and eventually melting at more elevated temperatures. Exothermic reactions are related to recrystallization at high temperatures that may be nearly concurrent with or after dehydroxylation and melting (Guggenheim and van Groos, 2001).

Throughout these years considerable research has been carried out in studying the effect of traditional stabilizers such as lime on engineering properties of the soil (Locat *et al*., 1990; Bell, 1996; Narasimha Rao and Rajasekaran, 1996). However, publications on the thermal characteristics of lime treated soils have been limited. In the present paper an attempt was made to study the effects of curing time on the thermal properties of lime stabilized soils.

Materials and experimental programme

Materials
In this research, a native tropical soil (i.e., laterite clay) was used for laboratory experiments. The more important features of this soil are as follows:

a) Noticeable acidic nature (pH= 4.86).

b) High amounts of free iron oxides (The main cause of its reddish colour).

c) High specific surface area value.

d) Presence of kaolinite as the dominant clay mineral.

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In addition, bentonite comprised mainly of sodium-montmorillonite was used in this investigation as reference sample. The bulk soil was purchased in 50 kg bags from Wyoming (United States). The engineering properties and chemical composition of untreated soil are presented in Table 1.

Table 1. The engineering properties and chemical composition of the natural soil.

ENGINEERING PROPERTIES	VALUES		CHEMICAL COMPOSITION (Oxides)	VALUES (%)	
	LC*	GB*		LC	GB
CEC (meq/100 g)	14.88	78.79	**SiO_2**	21.55	60.79
pH (L/S = 2.5)	4.86	9.03	**Al_2O_3**	24.31	21.20
Specific Gravity	2.75	2.64	**Fe_2O_3**	29.40	6.46
Liquid Limit, LL (%)	75.8	301.60	**Na_2O**	0.07	6.14
Plastic Limit, PL (%)	39.60	41.80	**K_2O**	0.11	(-)
Plasticity Index, PI (%)	36.20	259.80	**P_2O_5**	16.71	(-)
BS Classification	MH	CE	**SO_3**	3.98	(-)
ICL (%)	5.00	7.00	**CO_2**	3.65	1.19
Maximum dry density (Mg/m^3)	1.33	1.27	**MgO**	(-)	3.26
Optimum moisture content (%)	34.00	37.70	**CaO**	(-)	0.96
UCS (kPa)	288.10	281.30	**Soluble P (ppm)**	0.40	0.50
Loss of ignition (%)	6.32	(-)*	**Soluble Al (ppm)**	0.05	250
* LC: Laterite Cay, GB: Green Bentonite			**Soluble SiO_2 (ppm)**	0.10	40
(-): not detected.			**Soluble Ca (ppm)**	0.10	0.04

Preparation of specimens

The full-scale testing samples were prepared and cured in a similar manner to that described in the British Standard (BS 1924: Part 2: 1990). Based on the previous studies conducted on lime stabilized soils (Bell, 1996), two percentages of lime (i.e., 3% and 7%) by weight of the dry soil were chosen for this investigation.

Testing program

A TGA/SDTA851 instrument which is a modern device for TGA and simultaneous difference thermal analysis (SDTA) of materials was used in this study. This technique is based on monitoring the weight loss of the material during a controlled heating process in a defined gas atmosphere. Hence, small amounts of the sample was placed in an aluminum crucible under N_2 gas atmosphere with a flow rate of 10 mL/min and analyzed up to 850ºC at a rate of 10ºC/min.

Results and discussion

Figure 1 shows the thermal gravimetric curves of natural and 8 months cured lime treated bentonite and lateritic soil. As can be seen, soil dehydration covered the lower temperature regions. This weight loss was due to the evaporation of the adsorbed water on the surface and inter-layer of clay minerals. In laterite clay samples, considerable amount of organics were also present. The weight loss at temperatures around 300°C was due to this phenomenon. The losses at temperature ranges between 450ºC and 650ºC observed in all mix designs was due to the dehydroxylation of clay minerals (Guggenheim and van Groos, 2001). On the other hand, evaluation of the TGA results for the 8 months cured lime mix designs revealed a new drop at around 285ºC for bentonite samples. The latter was caused by the evaporation of moisture encapsulated into the cementitious compounds. In Fig. 2, the unconfined compressive strength of 3% and 7% lime treated soils after 1, 4, and 8 months of curing are shown. As can be seen, an increase of approximately 11-fold in the strength of lime treated bentonite in comparison to the natural soil was obtained.

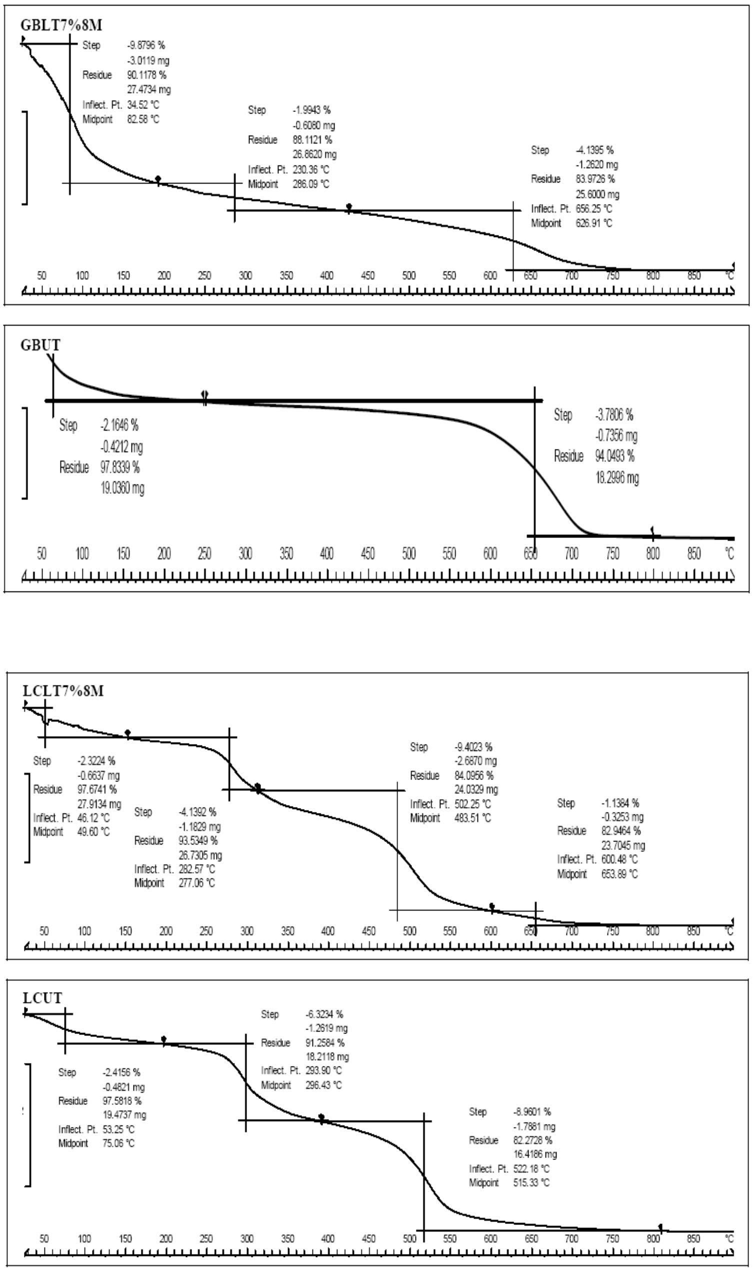

Figure 1. TGA spectrums of natural and 7% lime treated bentonite (Top) and laterite (Bottom) after 8 months of curing.

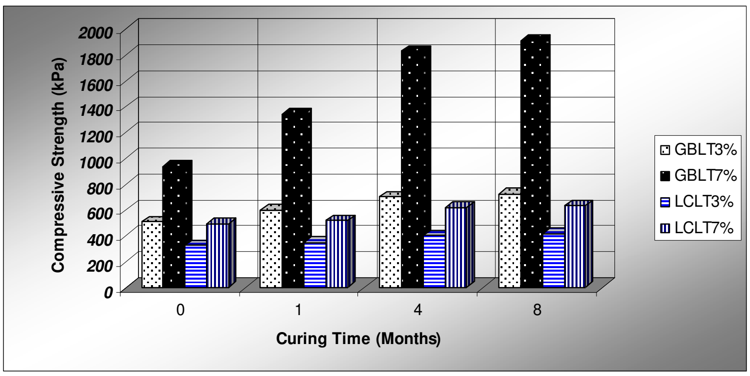

Figure 2. Strength development for Green Bentonite (GB) and Laterite Clay (LC) mix designs with curing time.

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Conclusions

In this paper, an analytical technique that was linked to the thermal characteristics of soil was conducted at different time intervals. This was carried out in an attempt to further elucidate the effects of lime on soil's properties. In lime treated bentonite samples, after 8 months of curing, new weight losses due to the evaporation of moisture encapsulated into the crystallized reaction products was seen. Also, it was found that the application of lime as a soil stabilizer had a marginal impact on the thermal properties of lateritic soil. From geotechnical point of view, lime treatment was more beneficial in enhancing the engineering properties of montmorillonite-rich soil (bentonite) over the 8 months time interval.

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