

MINERALOGY IN SILTY TO LOAMY SOILS OF CENTRAL AND HIGH BELGIUM IN RESPECT TO AUTOCHTHONOUS AND ALLOCHTHONOUS MATERIALS

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ABSTRACT. - Four different groups of silty to loamy soils in Belgium are distinguished : (1) soils on loess in Central Belgium; (2) soils on loess in High Belgium; (3) soils developed in situ on the parent rock (indicated as phyllites) in High Belgium and (4) soils developed in old weathering loam in situ or on solifluction material in High Belgium. From these different groups of soils extensive physico-chemical, chemical and mineralogical data are collected in order (1) to improve the existing knowledge on the composition of the soils and (2) to use them for a better founded interpretation of the origin of the different parent materials and the nature of the pedogenetic processes. The qualitative mineralogical composition is rather similar in the different groups of soils, but X-ray diffraction and total chemical analysis have shown some important quantitative differences inducing different pedogenetic processes. It is observed that the loess of Central Belgium has (1) very often Tertiary glauconite contaminating both sand and clay fractions, and (2) that his composition differs from the loess of High Belgium. It appears that (1) the homogeneity of the typical soils of the Ardennes can be approached through the study of the chemical composition and (2) that loess contamination in the soils on the highest plateaus of the Ardennes cannot be shown. The presence and the distribution of of the crystalline FeOOH minerals, goethite and lepidocrocite, throughout the profiles give some indications on the relative age of the different deposits.

1. INTRODUCTION.

In Belgium, two regions have dominantly silty to loamy soils. Region I is the loess belt of Central Belgium, having soils developed in an almost continuous cover of a dominant eolian material, loess. This eolian sediment, generally calcareous, was blown up out of the North Sea Basin during the Ice-ages and transported by north-west winds land inward (TAVERNIER, 1947). The upper meter(s) have been deposited during the Weichsel Pleniglacial B or Upper Weichsel) (HAESAERTS and VAN VLIET, 1974; PAEPE and VANHOORNE, 1976). Toward High Belgium the loess cover gradually thins and becomes very discontinuous.

The soils developed in these materials have presently a textural B horizon or argillic horizon (SOIL SURVEY STAFF, 1975), which

is characterized by an accumulation of clay leached from the A horizons. At some places these soils show bleached clay-poor tongues starting in the A horizons and penetrating into the clay-enriched horizons. This process of destruction of the argillic horizon is called "degradation".

Region II is the Massif of the Ardennes, having soils which are developed either in a solifluction layer, or in the "weathering loam" of the underlying bedrock. This bedrock is mainly composed of phyllites, a mixture of fine textured sandstones and shales, and quartzophyllades of Paleozoic age. The soils are characterized by a weathering horizon or cambic horizon with stable crumb structure, sometimes overlying a horizon with weak clay accumulation (DE CONINCK et

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al., 1979; LANGOHR and VAN VLIET, 1979).

During the systematic soil survey of the Massif of the Ardennes, it was assumed that in many soils, even on the high plateaus, an admixture of loess had taken place (PECROT and AVRIL, 1954, 1958). This was based mainly on texture and colour characteristics. Most of the soils of the Ardennes were considered to be very heterogeneous, because of this loess admixture and solifluction and erosion processes. On the other hand the eolian loess of Central Belgium was considered to be very homogeneous, so that in this material pedogenetic processes, like clay migration, were very often the subject of computation or numerical expressions (VAN WAMBEKE, 1972).

We have tried to improve the existing knowledge on the composition of the soils in these two regions with extensive mineralogical and chemical data and to use these data for a better founded interpretation of the origin of the parent material.

2. MATERIALS.

Four different groups of soils can be distinguished : (1) soils on loess in Central Belgium; (2) soils on loess in High Belgium; (3) soils developed in situ on the parent rock (indicated as phyllites) in High Belgium; (4) soils developed on old weathering loam in situ or on solifluction material in High Belgium. The distinction between the soils on phyllites, on weathering loam and on solifluction material is based on geomorphological characteristics : in the soils on phyllites, the unweathered parent rock is present at shallow depth; their situation indicates a strong erosion and subsequent rejuvenation. The soils on weathering loam are on plateaus, covered by a thick layer of old, weathered material. The position in the landscape of the soils on solifluction suggests that material has been added by solifluction. From every group a number of representative profiles under forest has been described and sampled (Fig. 1).

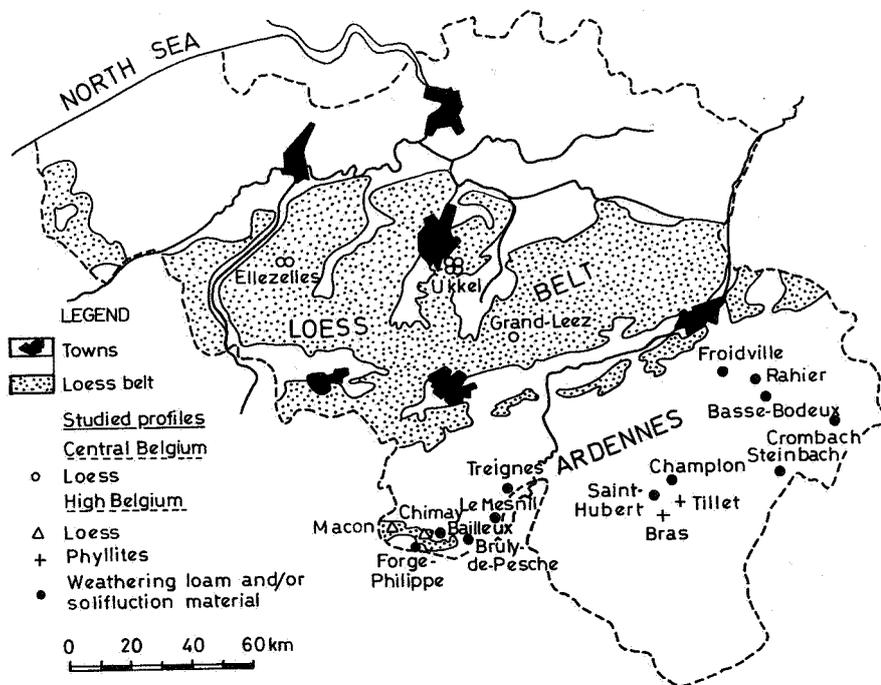


Fig. 1 - Location of the studied profiles.

From all these profiles detailed physico-chemical, chemical and mineralogical data have been obtained (VAN RANST, 1981).

In this paper are given the physico-chemical and mineralogical data of one representative profile of the four groups.

3. METHODS.

3.1. PARTICLE SIZE DISTRIBUTION AND SEPARATIONS OF FRACTIONS.

The fine earth (< 2 mm) was separated by sieving on a 2 mm sieve. After a pre-treatment with 30% H₂O₂ in order to destroy

the organic matter, the sand fraction (> 50 μm) was separated by wet sieving. The silt and clay fractions were determined after dispersion with 2% sodium-hexametaphosphate, using the pipette method of Köhn. The silt and the clay fractions were separated with successive sedimentation after dispersion with a solution of 2% Na₂CO₃.

3.2. DETERMINATION OF pH.

The pH was recorded in a ratio of soil to 1N KCl or of soil to H₂O of 1/1.

3.3. ORGANIC CARBON (O. C.) (BLACK, 1965).

The organic matter was determined by

adding a strong oxidizing agent, $K_2Cr_2O_7$, in a solution of H_2SO_4 . After 30 min., the excess of $K_2Cr_2O_7$ was back-titrated with 1N $FeSO_4$ in the presence of H_3PO_4 and an indicator solution.

3.4. DITHIONITE-EXTRACTABLE Fe_2O_3 and Al_2O_3 (DE CONINCK and HERBILLON, 1969).

Reduction of the free iron oxides with Na-dithionite, added in powder to a Na citrate-Na hydrogen carbonate solution of pH 7.3, at a temperature of 75°C. The reduced Fe was determined colorimetrically with ortho-phenantroline (Fe_2O_3 dith.). Free aluminium (Al_2O_3 dith.) was determined by atomic absorption.

3.5. TOTAL CHEMICAL ANALYSIS (INGAMELLS, 1966; OMGANG, 1969)

- Fusion of 100 mg. of sample with Li_2CO_3 and H_3BO_3 at 1000°C. The melt was dissolved in conc. HCl. Si and Al were determined by atomic absorption in a N_2O -acetylene flame. Ti was determined colorimetrically with chromotropic acid.

- Treatment of 100 mg of sample with HF + HNO_3 + $HClO_4$ until the solution was clear; the evaporation residu was dissolved in conc. HCl. Na, K, Ca, Mg and Mn were determined by atomic absorption in air-acetylene flame. Fe was determined colorimetrically with sulfosalicylic acid, P with ammonium vanadate and ammonium molybdate.

The difference total Fe_2O_3 - Fe_2O_3 dith. is dubbed Fe_2O_3 lat. (lattice). In the same way total Al_2O_3 - Al_2O_3 dith. = Al_2O_3 lat.

Recalculation of the contents of all elements on 100% after Fe_2O_3 dith. and Al_2O_3 dith. have been subtracted from total Fe_2O_3 and total Al_2O_3 respectively gives the "silicate" fraction.

3.6. HCl TREATMENT (DE CONINCK et al., 1975)

500 mg of material were treated overnight at 80°C in 1N HCl. The solid was separated from the extracting solution by centrifugation, washed with acetone and alcohol until free of Cl⁻ and used for X-ray diffraction. In the solution Al, Fe, Mg and K were determined in a way similar to the total chemical analysis. This treatment was carried out in order to dissolve selectively the chlorite and its transformation minerals (BRINDLEY, 1961). Untransformed mica minerals, except glauconite, are not attacked by HCl (VAN RANST, 1980).

3.7. X-RAY DIFFRACTION.

All the X-ray determinations were done on samples oriented parallel on glass slides. The 2-50 μm and also the 0-2 μm fractions were first used without any further treatment and were therefore Na⁺ saturated; when the HCl extraction was carried out, the treated samples were not saturated again. Dithionite-treated and also HCl-treated clay samples were run in Mg⁺⁺ and K⁺ saturated form. Glycol solvation of the Mg⁺⁺ saturated sample was carried out in vacuum with glycol vapor during 24 hours. The different heat treatments were always made during 2

hours. The diffraction was carried out with a Philips X-ray apparatus (PW 1050/25) with CoK_{α} radiation.

4. RESULTS.

4.1. SOME PHYSICO-CHEMICAL CHARACTERISTICS (Table 1).

All the studied profiles have a similar particle size distribution with a clear dominance of the silt fraction. The evolution of the clay percentage shows the presence of a clay-enriched or argillic horizon in the loess soils. In the soils on phyllites and in weathering loam, the clay content has a rather clear trend to increase upward, although the clay distribution in the soils in weathering loam is mostly irregular. In some profiles two maxima can be distinguished: a first one in the lower B horizons as a result of clay accumulation and a second one in the surface horizons as a result of an increasing weathering toward the top.

4.2. MINERALOGY

4.2.1. CENTRAL BELGIUM

4.2.1.1. PARENT MATERIAL (Fig. 2)

The 2-50 μm fraction of the calcareous loess contains dominantly quartz (spacings at 4.26 and 3.33 Å) and feldspars (spacings at 3.23 and 3.20 Å); chlorite (spacings at 10, 5 and 3.33 Å) and amphiboles (spacing at 8.5 Å). The HCl treatment completely destroys the 14 and 4.7 Å spacings, showing the presence of primary chlorite. The persistence of weak 7.2 and 3.55 Å rays may be due to an incomplete dissolution of the chlorite or to the presence of small amounts of kaolinite.

The 0-2 μm fraction is dominated by smectite (indicated by the 15 Å reflection when Mg⁺⁺ saturated shifting toward 18 Å after glycol solvation), mica, kaolinite, quartz, feldspars and interstratified minerals or mixed layers, indicated by the 24 and 12 Å rays in the K⁺ saturated sample. The 24 Å spacing collapses completely to 10 Å after heating at 350°C. The absence of reflections with spacings higher than 10 Å after heating is an indication that untransformed chlorite layers are absent.

The HCl treatment dissolves (1) trioctahedral minerals, possibly formed by transformation of chlorite and of trioctahedral micas (biotites), and/or (2) dioctahedral minerals, viz. nontronite, formed by transformation of glauconite. Dioctahedral smectites with an aluminous structure are not dissolved by HCl. Since in the studied samples part of the smectite is dissolved and part is left, it is obvious that two kinds of smectite are present.

The 0-2 μm fraction of the Tertiary glauconite substratum (Fig. 3), underlying the C₂ (ca) horizon in this particular case, has X-ray patterns before and after HCl treatment which are comparable to the 0-2 μm of the C₂(ca) horizon. This feature suggests that Tertiary material is mixed in the C₂(ca) horizon.

4.2.1.2. SOIL MATERIAL.

The mineralogical composition described for the material parent material is completely recovered in the soil materials.

The composition of the 2-50 μm fraction (Fig. 4) is similar in all the loess soils: quartz, feldspars, trioctahedral chlorite, mica and mostly amphiboles. Toward the top the intensities of chlorite, mica and amphiboles decrease clearly. However, the spacings of chlorite and mica do not show any clear features, which indicate a transformation of these minerals. This is an argument in favor of physical breakdown; a chemical weathering would cause a clear broadening or bridging of the 10 and the 14 \AA spacings and commonly strong to medium reflections of more than 20 \AA between 10 and 14 \AA . This physical fragmentation process must give rise to an absolute accumulation of chlorite and mica in the clay fraction and thus an absolute accumulation of clay, which becomes stronger closer to the surface.

The 0-2 μm fraction before dithionite treatment (Fig. 4) is dominated by 2/1 phyllosilicates with variable basal spacing and interstratified minerals, shown by a broad reflection between 10 and 14 \AA which collapses almost completely to 10 \AA after heating at 350°C. The 14 \AA peak remaining after heating in the A2 horizon indicates chloritic layers. This fraction further contains mica, kaolinite, quartz and feldspars. The specific reflections of the last two minerals are more intense in the A horizons. No indications for goethite and/or lepidocrocite could be found.

The 0-2 μm fraction of the Bt horizons after dithionite treatment (Fig. 5) shows that the greater part of the 2/1 phyllosilicates with variable basal spacing and of the interstratified minerals swells after glycol solvation. The 18 and the 9 \AA spacings in the glycol solvated Mg^{++} saturated sample indicate smectite. In the A horizons, the intensities of smectite strongly decrease

Profile	Hor.	Depth cm.	Texture			pH		O.C.
			clay 0-2 μm	silt 2-50 μm	sand 50 μm - 2 mm	KCl	H ₂ O	
<u>CENTRAL BELGIUM</u> Loess UKKEL altitude : 120 m	A	0-8	11.05	79.65	9.30	3.1	3.8	5.30
	A2	8-50	8.93	81.28	9.79	4.0	4.4	0.57
	B2t	50-120	21.30	70.33	8.37	3.8	4.9	0.17
	B3t	120-220+	18.53	71.70	9.77	3.9	4.8	0.26
<u>HIGH BELGIUM</u> Loess MACON altitude : 285 m	A1	0-20	11.65	84.35	4.00	3.3	4.0	9.25
	A2g	20-50	20.60	74.70	4.70	3.7	4.3	0.55
	B2tg	50-80	31.30	64.40	4.50	3.9	4.8	0.40
	B3tg	80-100+	27.00	68.20	4.80	3.8	5.0	0.30
<u>HIGH BELGIUM</u> Phyllites TILLET altitude : 511 m	A1	0-5	13.24	74.12	12.64	3.2	3.8	15.10
	(B)2	5-25	12.60	76.10	11.30	4.2	4.4	4.08
	(B)3	25-50	11.15	78.15	10.70	4.2	4.6	1.40
	C	50-100+	10.70	77.75	11.55	4.4	5.1	0.51
<u>HIGH BELGIUM</u> Weathering loam SAINT-HUBERT altitude : 560 m	A1	0-25	22.50	65.70	11.80	3.7	4.0	5.45
	(B)2	25-60	16.03	73.58	10.39	4.3	4.8	0.66
	B'2txg	60-95	20.20	68.15	11.65	4.2	4.8	0.33
	B'3txg	95-115+	20.50	70.05	9.45	4.2	4.8	0.46

Table 1 - Particle size distribution in %, pH in KCl and in H₂O in a ratio 1:1; and organic carbon (O.C.) in %, in 4 representative profiles.

and in some studied A2 horizons, smectites are almost completely absent, whereas in the A1 horizons smectites are noticed everywhere. The lower amount or absence of smectite and swelling mixed layers in the upper horizons and the concomitant increase of the quartz and of feldspars indicate a translocation of the former minerals, with formation of the well developed clay-enriched horizon. Another important mineralogical feature in these soils is the absence of untransformed chlorite in the lower horizons and its presence in the A horizons. These chloritic minerals in the upper horizons are the result of the physical breakdown of silt-size chlorite. In the A horizons, chlorite and mica gradually undergo a vermiculitisation, forming mixed layers. In many cases, the swelling stage, smectite is reached.

A detailed mineralogical study has not shown detectable differences between the non-degraded and the degraded loess soils: the degradation process of the B2t horizon is not coupled with a more pronounced mineralogical evolution than in the soils without degradation phenomena.

4.2.2. HIGH BELGIUM.

4.2.2.1. UNDERLYING PARENT ROCK (Fig. 6)

The typical soils of High Belgium with exception of a few loess deposits in the Thiérache and the Pays de Herve, have developed in situ on the parent rock or in "wea-

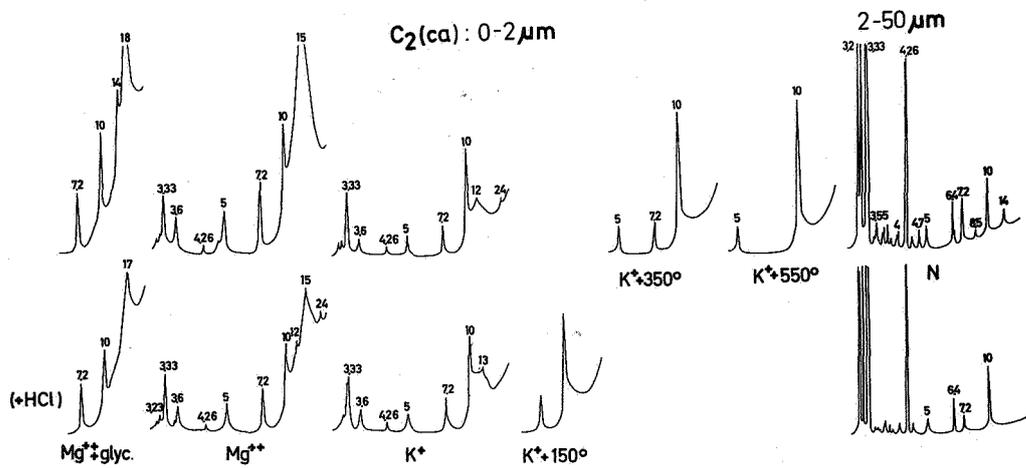


Fig. 2 - X-ray diffraction patterns of the 0-2 μm and the 2-50 μm fractions of the calcareous loess ($C_2(\text{ca})$) before (N - saturated Na^+) and after HCl treatment (saturated H^+), saturated Mg^{++} , Mg^{++} + glycol, K^+ and after heating at 150°, 350° and 550° C of the K^+ saturated sample.

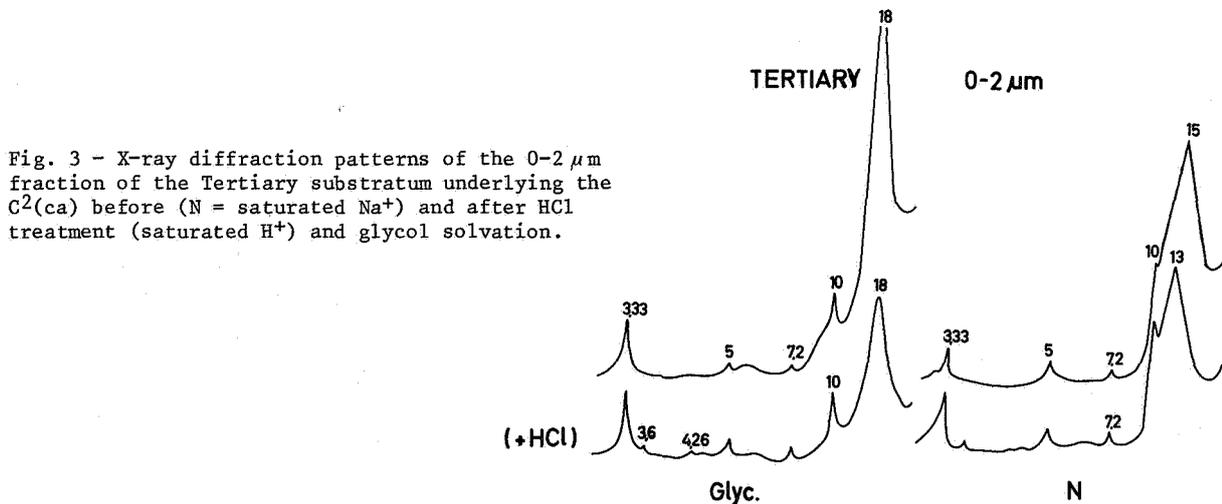


Fig. 3 - X-ray diffraction patterns of the 0-2 μm fraction of the Tertiary substratum underlying the $C_2(\text{ca})$ before (N = saturated Na^+) and after HCl treatment (saturated H^+) and glycol solvation.

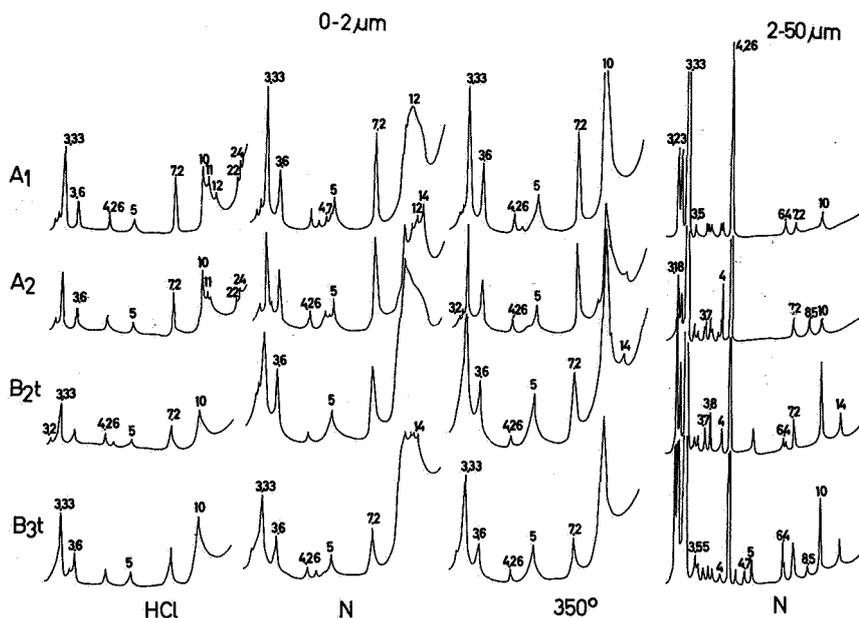


Fig. 4 - X-ray diffraction patterns of the 0-2 μm and the 2-50 μm fractions of a soil on loess in Central Belgium before (N = saturated Na^+) and after HCl treatment (saturated H^+) and after heating at 350°.

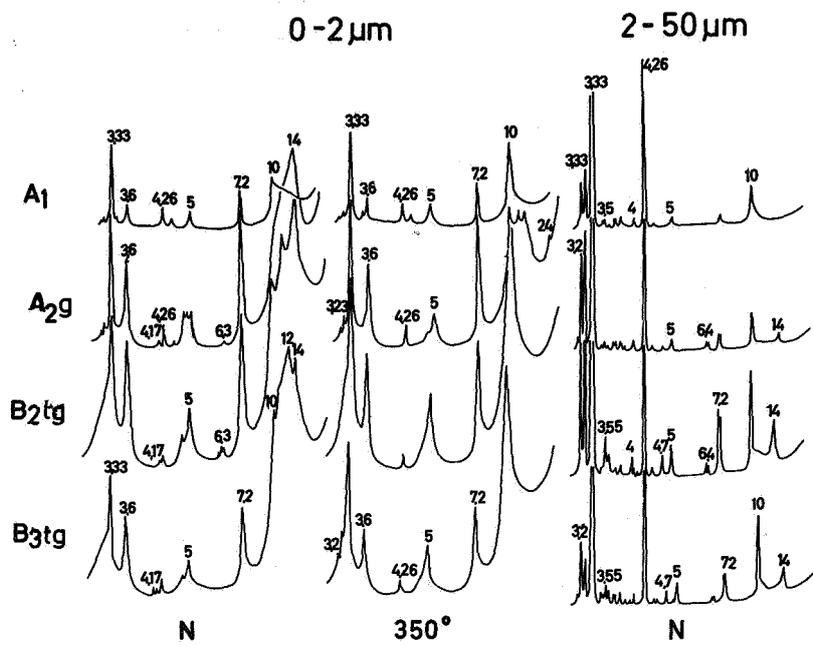


Fig. 7 - X-ray diffraction pattern of the 0-2 μm and the 2-50 μm fractions of a soil on loess in High Belgium saturated Na⁺ (= N) and after heating at 350° C.

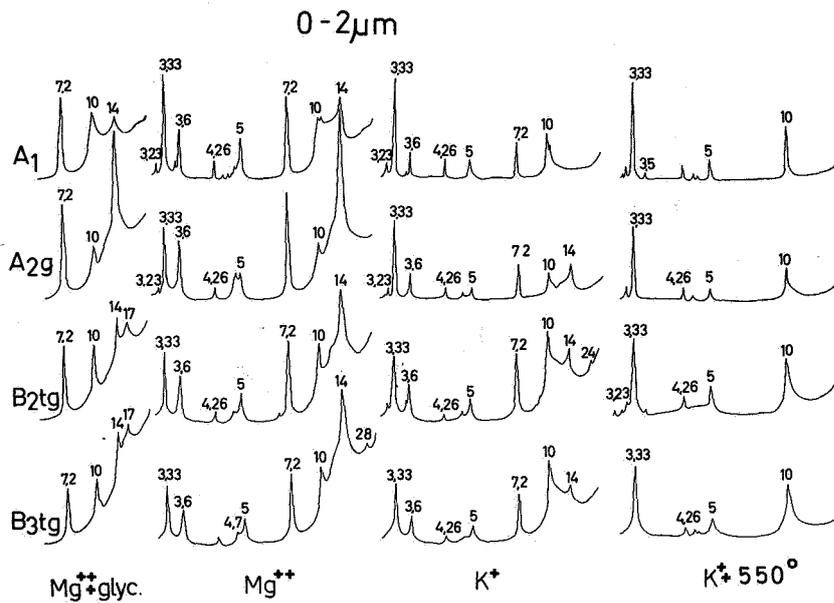


Fig. 8 - X-ray diffraction patterns of the 0-2 μm fraction of a soil on loess in High Belgium after dithionite treatment and saturated Mg⁺⁺, Mg⁺⁺ + glycol, K⁺ and after heating at 550°.

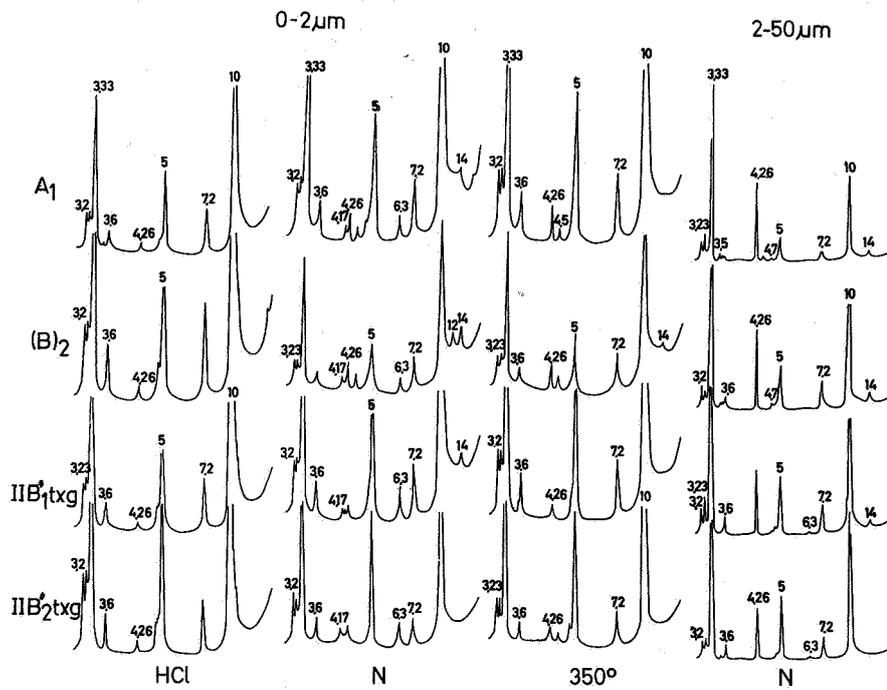


Fig. 12 - X-ray diffraction patterns of the 0-2 μm and the 2-50 μm fractions of a soil on solifluction material in High Belgium before (N = saturated Na⁺) and after HCl treatment (saturated H⁺) and after heating at 350°C.

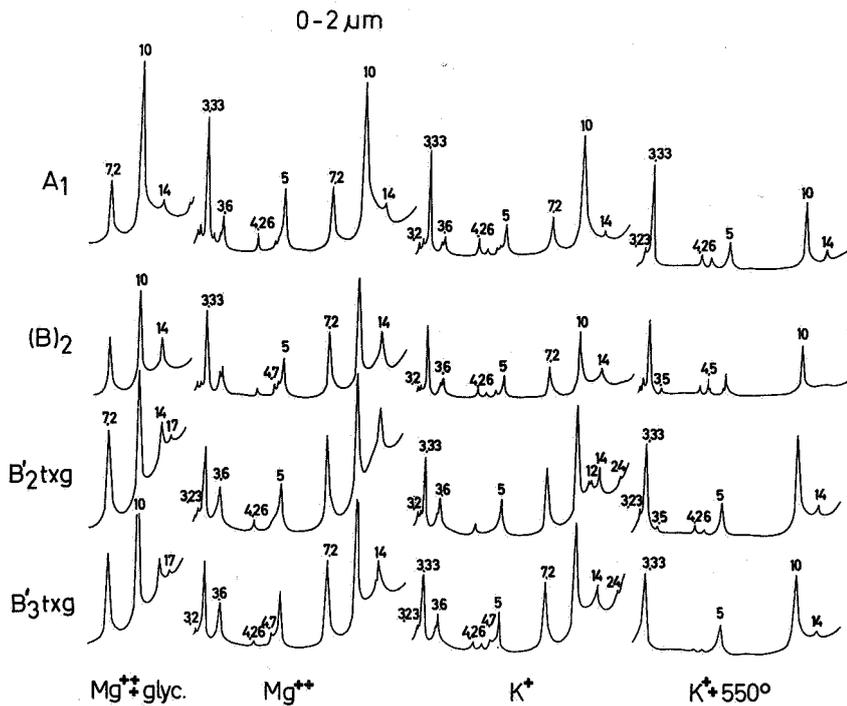


Fig. 13 - X-ray diffraction patterns of the 0-2 μm fraction of a soil on weathering loam in High Belgium after dithionite treatment and saturated Mg⁺⁺, Mg⁺⁺ + glycol, K⁺ and after heating at 550°C.

The upper horizons are again characterized by a decrease of the 14 Å ray, as the result of an increasing transformation of chlorite. The occurrence of a bridge between 10 and 14 Å after Mg⁺⁺ saturation indicates a gradual transformation of mica toward the top.

4.3. CHEMICAL ANALYSES.

4.3.1. DITHIONITE-EXTRACTABLE Fe₂O₃ AND Al₂O₃ (TABLE 2).

The amounts of Fe₂O₃ and Al₂O₃ extracted with dithionite in the 0-2 mm and in the 0-2 μm fractions are always higher in the typical soils of the Ardennes, compared to the loess soils. This is an evident indication that the parent material of these soils originally had more weatherable Fe- and Al-bearing minerals, viz. trioctahedral chlorite and micas. This feature is most pronounced in the soils on phyllites. The loess soils of High Belgium have always intermediate values, except in the upper horizons, where the amounts of Fe₂O₃ are very low. This is the result of the poor drainage which is a general characteristic of these loess soils. These hydromorphic conditions have a reducing and mobilizing influence on the free iron compounds but leave aluminium unaffected.

In the 0-2 μm fraction, both Fe₂O₃ and Al₂O₃ increase upward in all soils, except in the loess soils of High Belgium, clearly expressing a gradually stronger release as a result of the increasing transformation of chlorite and mica. In the soils of the Ardennes in an old weathering loam, the amount of goethite and lepidocrocite, however, decreases in the same way and they have even disappeared in the A1 horizons. This may indicate that the presence of organic substances either prevents the crystalline iron compounds to form or causes their change into amorphous compounds during the soil development.

Profile	Hor.	0-2 mm		0-2 μm	
		Fe ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃	Al ₂ O ₃
<u>CENTRAL BELGIUM</u> Loess	A1	1.02	0.31	7.72	1.64
	A2	0.76	0.31	4.87	2.10
	B2t	1.44	0.60	4.90	1.51
	B3t	1.50	0.39	5.82	1.23
<u>HIGH BELGIUM</u> Loess	A1	0.44	0.32	1.09	2.15
	A2g	1.40	0.24	3.49	1.68
	B2tg	2.30	0.69	5.37	1.84
	B3tg	2.32	0.45	4.40	1.36
<u>HIGH BELGIUM</u> Phyllites	A1	2.76	1.07	13.15	4.94
	(B)2	3.39	1.84	13.99	6.76
	(B)3	2.26	0.99	10.16	3.47
	C	1.52	0.67	6.24	3.09
<u>HIGH BELGIUM</u> Weathering loam	A1	2.68	0.78	6.62	2.04
	(B)2	2.59	0.90	5.85	3.69
	B'2txg	2.49	0.66	6.16	1.73
	B'3txg	2.49	0.69	5.64	1.41

Table 2 - Dithionite-extractable Fe₂O₃ and Al₂O₃ in % of the 0-2 mm and the 0-2 μm fractions of 4 representative profiles.

4.3.2. CHEMICAL COMPOSITION OF THE FINE EARTH (TABLE 3).

The total chemical composition of the total soil of the fine earth can give different informations. The loss on ignition at 1000°C, indicated in the tables as H₂O, includes the organic matter and all kinds of water, i. e. hygroscopic water, interlayer water and lattice water. Two features can be concluded from these data :

(1) the soils of High Belgium have a higher loss on ignition than the loess soils of Central Belgium. This feature indicates a greater organic matter content and a better developed macrostructure in the former soils, retaining more hygroscopic water;

(2) the evolution of the loss on ignition in the profiles is related to the profile development : in the soils with a horizon sequence A1, A2, B2t, the loss on ignition is lower in the A2 than in the B2t due to a greater content of "inactive" minerals, like quartz and feldspars, which are unable to retain water and to form a macrostructure with high porosity. In the soils with a horizon sequence A1, (B), C or A1, (B), B'2t, the hygroscopic water gradually decreases with a weaker development of the porous macrostructure with depth.

For the other elements, information can be gathered from the analytical data using following principles :

(1) the contents of elements which are present in only one kind or group of minerals give a direct value for the amount of these mineral present;

(2) the difference between the total and free amounts of an element represents the fraction of the element in the lattice of the silicates;

(3) comparison of total contents and ratios between different elements gives useful information concerning pedological processes and homogeneity of the parent material.

The application of these three principles in the studied soils.

(1) The soils on loess have less K₂O and MgO but more CaO + Na₂O than the other soils. Combined with the higher amount of SiO₂ in the former, it can be concluded that the loess soils have more feldspars and quartz, and less micas and chlorite. This is confirmed by the distribution of the SiO₂/K₂O and to a lesser extent of the SiO₂/MgO ratios, presented in Fig. 14.

(2) The amounts of total Fe₂O₃ - Fe₂O₃ dith. = Fe₂O₃ lat. and total Al₂O₃ - Al₂O₃ lat. can be considered as an approximate approach of the amount of Fe and Al present in the silicates. Fig. 14 shows that Al₂O₃ lat. is definitely lower in the loess soils than in the other soils, suggesting that the latter have more kaolinite. As for Fe₂O₃ lat., the soils on phyllites are notably richer in it, whereas the separation between loess soils and soils on weathering loam and solifluction material is not evident. This confirms that especially the soils on phyllites have more trioctahedral chlorite.

Profile	Hor.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	CaO	Na ₂ O	TiO ₂	MnO	P ₂ O ₅	H ₂ O	Tot.
<u>CENTRAL BELGIUM</u> Loess	A1	81.22	5.52	1.98	0.37	1.59	0.31	0.88	0.43	0.03	0.10	6.43	98.86
	A2	84.46	5.93	1.83	0.38	1.70	0.33	0.93	0.42	0.06	0.09	3.18	99.31
	B2t	78.44	7.68	3.97	0.71	1.85	0.32	0.83	0.43	0.07	0.05	4.90	99.25
	B3t	78.17	7.64	3.85	0.79	1.88	0.49	1.07	0.51	0.09	0.18	4.29	98.96
<u>HIGH BELGIUM</u> Loess	A1	76.34	6.20	0.82	0.14	1.46	0.13	0.75	0.62	0.01	0.08	14.35	100.90
	A2g	81.90	7.46	2.45	0.19	1.72	0.15	0.84	0.66	0.03	0.01	4.74	100.15
	B2tg	71.31	11.12	5.34	0.75	2.01	0.15	0.78	0.72	0.05	0.01	7.56	99.80
	B3tg	73.22	10.24	4.54	0.72	1.87	0.28	0.96	0.70	0.07	0.01	6.62	99.23
<u>HIGH BELGIUM</u> Phyllites	A1	45.31	8.73	4.64	0.46	1.56	0.08	0.18	0.54	n.d.	0.22	37.37	99.09
	(B)2	62.15	12.60	6.20	0.95	2.10	0.06	0.23	0.67	n.d.	0.10	14.64	99.70
	(B)3	64.18	14.56	6.92	1.39	2.36	0.01	0.24	0.76	n.d.	0.15	8.50	99.07
	C	66.30	14.75	6.71	1.74	2.77	0.01	0.27	0.73	n.d.	0.09	5.98	99.35
<u>HIGH BELGIUM</u> Weathering loam	A1	67.64	10.06	3.52	0.34	1.64	0.12	0.62	0.46	n.d.	0.06	15.60	100.06
	(B)2	74.09	12.09	3.80	0.55	1.93	0.13	0.72	0.52	n.d.	0.01	6.11	99.95
	B'2txg	72.75	12.92	4.44	0.61	2.15	0.12	0.71	0.52	n.d.	0.01	5.18	99.41
	B'3txg	70.53	14.38	4.37	0.53	2.35	0.08	0.79	0.56	n.d.	0.01	5.11	98.70

Table 3 - Chemical composition of the fine earth in % of 4 representative profiles; H₂O represents the loss on ignition at 1000°C.

(3) The variation in absolute contents or (molar) ratios shows two divergent patterns.

a) Consistent changes in the contents or the ratios indicate pedological processes :

- physical breakdown of coarse grains into fine grains does not change the ratios in the total soil;
- chemical weathering with release of the elements present in the minerals results in an export of the soluble elements (Ca, Mg, K, Na) and a relative increase of the insoluble elements (Si, Al, Fe, Ti, P). Thus in the total soil the ratios of Si on the former elements increase, but are constant on the latter elements (Al, Fe, Ti, P);
- clay migration causes a relative accumulation in the eluviated horizons of the elements composing the immobile minerals, e.g. quartz, feldspars, and an absolute accumulation of the elements composing the mobile minerals, e. g. smectite and vermiculite, in the Bt horizon.

b) Inconsistent or abrupt changes suggest that the parent material is heterogeneous.

Two examples are shown in fig. 15.

- The weathering loam has consistent patterns for the different considered ratios, with a gradual decrease with depth of Si, relative to A, Fe, K, Mg and Ca + Na. These patterns are explained by a weak downward clay translocation and by weathering of micas, trioctahedral chlorite and feldspars in the upper horizons.
- On solifluction material the patterns are inconsistent, showing lower values of the different ratios in the top horizons than in the underlying horizons. This inconsistency can be explained only by addition of allochthonous material poorer in Si at the top, possibly by solifluction.

Table 3 gives the values of the chemical composition of the fine earth in the four groups of soils. In the soils on loess, the strong translocation of clay out of the A into the Bt horizons is evident in the increase of Al₂O₃ from A to Bt horizons. The same process, in combination with weathering of trioctahedral chlorite, explains the differences in Fe₂O₃ and MgO contents between A and Bt horizons. The smaller changes in K₂O and CaO + Na₂O indicate that micas and feldspars are less subject to weathering and translocation than minerals having layers with variable basal spacing. In the soils on phyllites and on weathering loam, the variations in the contents of SiO₂, Al₂O₃ and Fe₂O₃ throughout the profiles are smaller with, however, a weak tendency for SiO₂ to increase upward relative to Al₂O₃ and Fe₂O₃. This may denote a weak clay migration. The stronger increase of SiO₂ relative to MgO and K₂O expresses the weathering of trioctahedral chlorite and mica. Feldspars are rather constant throughout the soils.

4.3.3. CHEMICAL COMPOSITION OF THE CLAY FRACTION.

The chemical composition (Table 4) and the molar ratios of the silicate fraction (Fig. 16) present the following features :

(1) the loess soils from Central Belgium and High Belgium have more SiO₂ than the soils on phyllites and on weathering loams; thus more quartz in the clay fraction;

(2) the loess soils do not have an identical composition : in High Belgium the Al₂O₃ and CaO + Na₂O contents are higher indicating more kaolinite and/or feldspars; the amounts of mica and chlorite minerals are, however, comparable;

(3) the soils from High Belgium without loess have lower SiO₂/Al₂O₃ and SiO₂/K₂O and higher SiO₂/Fe₂O₃ and SiO₂/MgO ratios : more kaolinite and micas, but less chloritic minerals than the loess soils. The higher contents of Fe₂O₃ dith. especially in the soils on phyllites (Table 2) suggest, however,

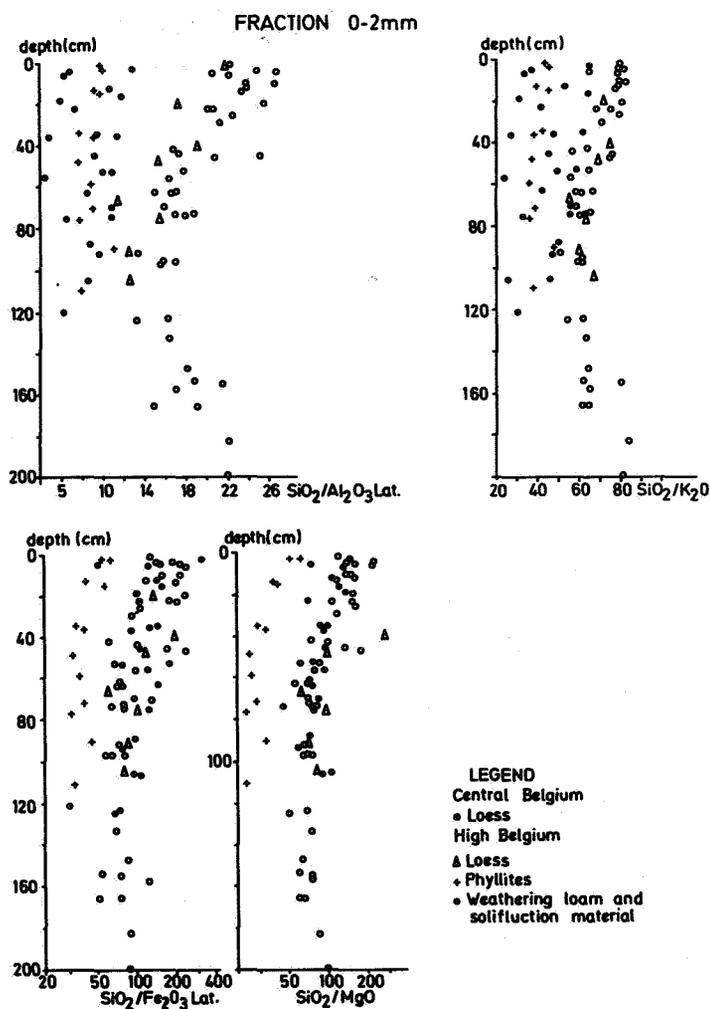


Fig. 14 - Distribution of different molar ratios of the "silicate" fraction of the fine earth in the different groups of soils. The molar ratios on Al and K are represented on a linear scale and those on Fe and Mg on a logarithmic scale.

that these soils originally had a higher amount of Fe-bearing silicates.

4.3.4. HCl TREATMENT OF THE CLAY FRACTION (TABLE 5).

The applied treatment completely dissolves trioctahedral chlorite, transformation products of this mineral and glauconite (DE CONINCK, 1976). But experiments on soils containing muscovite and biotite have shown that muscovite and biotite are partly attacked especially the fraction which is already transformed into mica-vermiculite or mica-smectite (DE CONINCK et al., 1975, 1976).

In the loess soils of Central Belgium, HCl extracts 20-25% of total K in the A horizons and about 40% in the Bt horizons. These quantities exceed the values of extracted K

in the loess soils of High Belgium and suggest the presence of glauconite in the former loess. The maximum extraction in the B2t horizons can be explained by the preferential migration of glauconite and other partially transformed mica minerals.

The amounts of Mg and to a lesser extent of Fe extracted decrease toward the surface. The decrease of these elements, in the soils on phyllites, where the extraction of the mica increases upward, suggests that the upper horizons contain less chloritic minerals than the lower ones. The decrease of the extracted amounts of Mg and Fe in the other soils can partly be explained by the greater resistance of unweathered mica minerals in the top horizons.

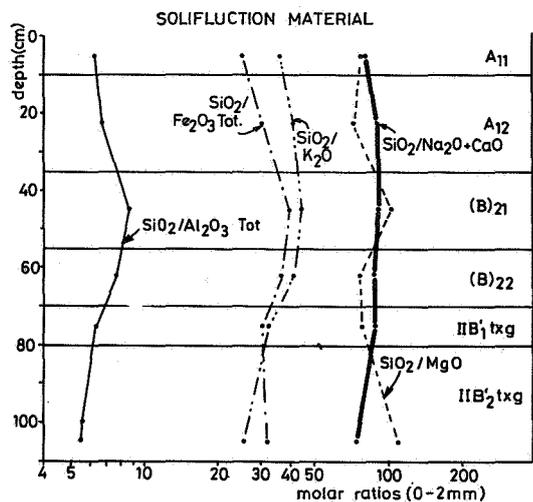
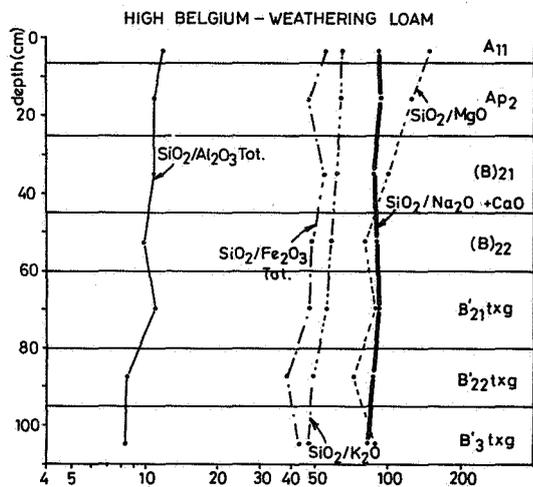
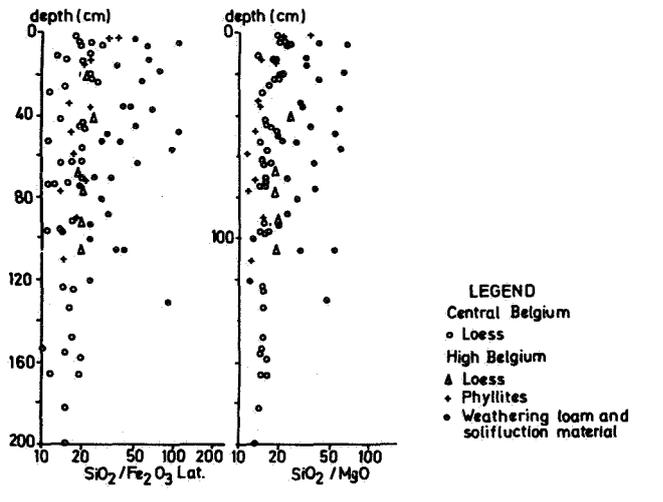
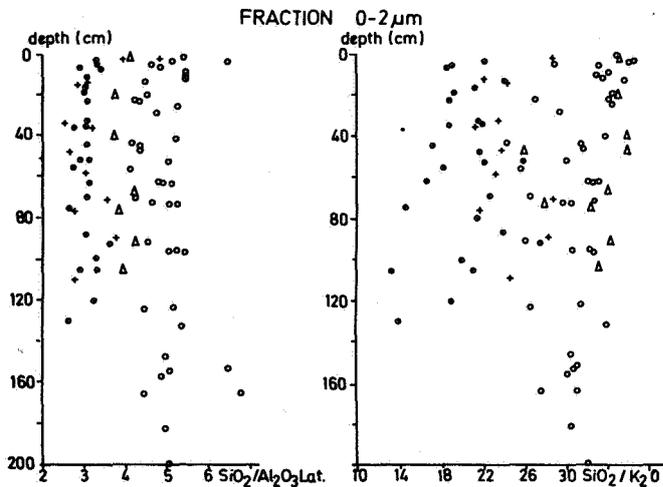


Fig. 15 - Evolution of different molar ratios of the fine earth in a profile on weathering loam and in one on solifluction material in High Belgium. The molar ratios are represented on a logarithmic scale.



LEGEND
 Central Belgium
 • Loess
 High Belgium
 ▲ Loess
 • Phyllites
 • Weathering loam and solifluction material

Fig. 16 - Distribution of different molar ratios of the "silicate" fraction of the 0-2 μm fraction in the different groups of soils. The molar ratios on Al and K are represented on a linear scale and those on Fe and Mg on a logarithmic scale.

Profile	Hor.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	CaO	Na ₂ O	TiO ₂	MnO	P ₂ O ₅	H ₂ O	Tot.
CENTRAL BELGIUM Loess	A1	47.50	16.30	13.22	1.27	2.18	0.12	0.77	0.85	0.09	3.22	13.71	99.23
	A2	47.34	19.94	10.73	1.61	2.24	0.12	0.63	0.78	0.16	1.79	13.87	99.21
	B2t	46.53	18.38	12.53	1.94	2.22	0.09	0.32	0.71	0.08	0.84	16.42	100.06
	B3t	46.80	17.25	12.96	2.04	2.40	0.43	0.52	0.70	0.16	0.65	15.36	99.27
HIGH BELGIUM Loess	A1	51.29	22.85	3.69	1.07	2.27	0.28	1.13	0.91	0.01	1.88	13.34	98.71
	A2g	47.29	22.82	8.63	1.23	2.05	0.18	0.93	0.74	0.02	0.96	14.80	99.65
	B2tg	46.77	20.33	11.94	1.63	2.14	0.24	1.26	1.08	0.10	0.36	14.10	99.95
	B3tg	47.33	20.27	10.52	1.59	2.15	0.29	1.31	0.93	0.08	0.58	14.81	99.86
HIGH BELGIUM Phyllites	A1	40.56	19.07	16.52	0.78	1.60	0.01	0.77	0.40	0.07	3.17	16.26	99.21
	(B)2	33.92	26.55	18.28	1.18	2.17	0.15	0.98	0.41	n.d.	1.19	15.02	99.85
	(B)3	34.98	26.45	15.99	1.65	2.30	0.15	1.16	0.40	0.16	0.88	14.90	99.02
	C	38.13	26.40	13.01	2.01	2.54	0.06	0.40	0.38	n.d.	1.02	15.12	99.07
HIGH BELGIUM Weathering loam	A1	44.78	26.28	9.35	0.87	3.25	0.12	1.54	0.78	0.11	0.68	11.65	99.41
	(B)2	42.43	27.47	8.47	0.97	3.00	0.17	1.30	0.82	0.19	0.73	13.96	99.51
	B'2txg	44.79	25.98	10.40	1.25	3.01	0.21	1.06	0.77	0.06	0.33	12.17	100.03
	B'3txg	46.09	25.51	8.96	1.02	3.46	0.19	1.21	0.62	0.05	0.90	11.02	99.03

Table 4 - Chemical composition of the 0-2 μm fraction in % of 4 representative profiles; H₂O represents the loss on ignition at 1000°C.

Profile	Hor.	I				II			
		Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O
<u>CENTRAL BELGIUM</u> Loess	A1	7.89	10.64	0.72	0.49	48.40	80.48	56.69	22.48
	A2	11.16	9.13	1.11	0.57	55.97	85.09	68.94	25.45
	B2t	12.09	10.52	1.40	0.90	65.78	83.96	72.16	40.54
	B3t	9.71	10.96	1.58	0.92	56.29	84.57	77.45	38.33
<u>HIGH BELGIUM</u> Loess	A1	9.45	2.44	0.56	0.28	41.36	66.12	52.34	12.33
	A2g	12.42	7.32	0.95	0.38	54.43	84.82	77.24	18.54
	B2tg	12.17	10.51	1.32	0.53	59.86	88.02	80.98	24.77
	B3tg	9.83	9.95	1.05	0.44	48.35	94.58	66.04	20.47
<u>HIGH BELGIUM</u> Phyllites	A1	9.92	13.78	0.64	0.22	52.02	83.41	82.05	13.75
	(B)2	14.59	17.27	0.92	0.29	54.95	94.47	77.97	13.36
	(B)3	11.21	13.90	1.37	0.20	42.38	86.93	83.03	8.70
	C	12.16	11.72	1.82	0.28	46.06	90.08	90.55	11.02
<u>HIGH BELGIUM</u> Weathering loam	A1	7.32	8.07	0.51	0.29	27.85	86.31	58.62	8.92
	(B)2	9.23	8.04	0.59	0.30	33.60	94.92	60.82	10.00
	B'2txg	9.19	9.48	0.83	0.45	35.37	91.15	66.40	14.95
	B'3txg	6.65	7.75	0.59	0.36	26.07	86.50	57.84	10.40

Table 5 - HCl 1N treatment of the 0-2 μ m fraction of 4 representative profiles;

I : extracted amounts in % of the total sample;

II : extracted amounts in % of the total content of the considered element.

The lower amounts of Al extracted in the typical soils of the Ardennes, especially in the soils on weathering loam, indicate that these soils contain more kaolinite and possibly more dioctahedral micas, viz. muscovites.

5. DISCUSSION.

5. 1. MINERALOGY AND PEDOGENETIC PROCESSES.

Quartz, feldspars, micas, kaolinite and minerals with trioctahedral chloritic structure are present in the parent material of all soils. The silt fraction of some soils contains amphiboles. The clay fraction of the loess is rich in smectite. Fine earth and clay fraction of the soils on loess have more quartz and feldspars, whereas the other soils are richer in micas and kaolinite. The composition of the loess is different in Central and High Belgium, the latter having more feldspars and kaolinite. The great amounts of free Fe and Al are indicative of the weathering of Fe-bearing minerals, viz. chlorite, biotite and amphibole in the typical soils of High Belgium. The loess soils from Central Belgium, resting at shallow depth on glauconiferous Tertiary deposits have this mineral in both sand- and clay fractions.

Weathering during the evolution of the soils occurs in two ways :

(1) physical weathering - This process is characterized by a physical breakdown of coarse grains into finer ones and can be noticed by the decrease toward the top of the soils of mica and especially trioctahedral chlorite in the silt fraction of most studied profiles. It results in a relative accumulation of the more resisting minerals, quartz and feldspars, in the silt and probably in the sand fractions.

(2) chemical weathering - This process can be either congruent or incongruent. The absence of amphiboles in the clay fraction suggests that these minerals are broken down congruently. The primary phyllosilicates can undergo an incongruent weathering : by losing either K⁺ or the trioctahedral hydroxide sheet, micas and trioctahedral chlorite are gradually transformed into layer silicates with variable basal spacing. The intermediate stage with a partial removal of the K⁺ or the OH sheet form vermiculitic or smectitic interstratified minerals. These minerals are common in most soils. Complete removal of K⁺ or the OH sheet gives smectite in some cases. It is obvious that this incongruent weathering or transformation is most expressed in soils with originally more mica and particularly more chlorite. It is, of course, possible that part of these minerals have been completely broken down.

The formation of the dominant diagnostic horizons is directly related to the mineralogical composition : the loess soils, with easily translocated smectite in the parent material, have a well-developed argillic horizon. The soils with more weatherable minerals have developed a cambic horizon with stable crumb structure. This crumb structure is related to the high amounts of free Fe and free Al resulting from the weathering of mica and trioctahedral chlorite.

5.2. HOMOGENEITY OF THE SOIL MATERIAL.

5.2.1. IN THE LOESS SOILS OF CENTRAL BELGIUM.

The loess soils of Central Belgium are very often considered as being developed in a homogeneous material. A detailed mineralogical

and chemical study has, however, shown that, at many places, the loess is contaminated with glauconite, originating from underlying Tertiary deposits. The amount of glauconite, as established by visual observation in the field, increases downward in the soils. In the clay fraction, the presence of glauconite can be recognized by its solubility in HCl 1N, as opposed to the resistance of the other micas in this solution. The high amount of K⁺ extracted from the clay fraction of the loess soils from Central Belgium suggests the presence of glauconite in this fraction. The analyses show an abrupt change in the amount of K⁺ extracted between the A and the B_{2t} horizons (20-25% compared to about 40%). This difference may be explained by the high mobility of clay-size glauconite (DE CONINCK and HERBILLON, 1969; VAN RANST and DE CONINCK, 1982). A translocation has occurred out of the A into the B_t horizons lowering the content in the former and increasing in the latter.

5.2.2. IN THE TYPICAL SOILS OF THE ARDENNES.

The homogeneity of these soils can be tested through the consistency in the chemical composition. As explained earlier, a decrease of the ratios of Si on the other elements to the top of the profiles cannot be explained by pedogenetic processes in the present soils. Since this characteristic can be established in some soils on slopes, it is evident that these soils have solifluction material mixed in the top horizons.

It is, however, not necessary that all soils with solifluction at the top show an inconsistent chemical pattern: if the solifluction material has a chemical composition similar to that of the original soil, it is difficult to establish the presence of the former material overlying the latter.

5.3. THE PROBLEM OF LOESS CONTAMINATION IN THE SOILS OF THE ARDENNES.

The soil map of Belgium (MARECHAL and TAVERNIER, 1974) delimitates some zones of soils with prominent argillic or textural B horizon developed in loess. The clay of the B horizon contains high amounts of smectite. These zones are situated in the border areas at lower altitude around the Ardennes (e.g. Thiérache, Pays de Herve).

These observations have lead to the concept that the continuous loess cover of Central Belgium grades into a discontinuous cover in High Belgium. It was assumed that the size of the particles would become smaller with increasing distance of transport. Moreover, different authors have mentioned the presence of loess material in the upper horizons of the typical soils of the Ardennes, even in those at the highest plateaus (PECROT and AVRIL, 1954, 1958). This idea was mostly based on field characteristics and in some cases on the study of the heavy minerals in the sand fractions (GULLENTOPS, 1954, 1957; TONNARD, 1957).

In order of loess material to be present on the highest plateaus, it had to bridge an elevation step of more than 200 m. Thus it must be expected that the finest fraction of the loess should dominate on the highest plateaus. The mineralogical study of

the loess material of Central Belgium has shown that the clay fraction is dominantly composed of smectite and interstratified minerals inherited from the parent material. Consequently these minerals should be present in clearly detectable amounts in the soils of the high plateaus, if loess would form an important part of the parent material. In reality, these minerals either are absent, or form only very small amounts, and the presence of the latter can be explained by a transformation process of micas and trioctahedral chlorite. Therefore, the mineralogy excludes the possibility for loess to be present in the Central Ardennes, e.g. the plateau of Saint-Hubert as well as in the surrounding places Champlon, Bras and Tillet at a somewhat lower altitude.

5.4. DISTRIBUTION OF GOETHITE AND LEPIDOCROCITE.

The presence of the crystalline FeOOH minerals, goethite and lepidocrocite, can give some indications on the relative age of the deposits. These Fe minerals show a specific distribution pattern.

(1) In the soils on loess.

In Central Belgium, these minerals are absent, except in the lowest horizon of the profile in Grand-Leez, which has been described in the field as an older material than the overlying loess. This interpretation was based on some differences in morphology. The loess soils of High Belgium have these minerals throughout the profile, except for some top horizons. These data suggest that the underlying loess of Grand-Leez and the loess of High Belgium are older than the loess of Central Belgium.

(2) In the typical soils of the Ardennes.

In these soils, three distribution patterns can be distinguished:

- in the soils on phyllites, they are absent;
- in the soils on weathering loam, they are absent in the top horizons but present in the lower horizons;
- in the soils on solifluction, they are present throughout the whole profile.

Two assumptions are generally admitted concerning these crystalline Fe minerals (SCHWERTMANN, 1966; DE CONINCK et al., 1979):

- goethite and lepidocrocite have been formed during older weathering periods with more tropical climate;
- under the actual conditions of temperate climate with more acidic and complexing organic substances, these minerals become unstable with time and are transformed into amorphous or complexed forms.

Applying these assumptions on the studied soils, the following conclusions can be drawn:

- the soils on phyllites are recent soils, without indications of an older weathering stage;
- the soils on weathering loam have been in place for a very long period; goethite and lepidocrocite had been formed throughout the profile, but in recent time, they have been transformed in the top horizons;

c. in the soils on solifluction, the soliflucted material is composed of old weathered material containing goethite and lepidocrocite; the period elapsed since its deposition has been too short to destroy the crystalline Fe minerals.

6. CONCLUSIONS.

(1) The qualitative mineralogical composition is rather similar in the different groups of soils, but the relative intensities of the respective minerals and the chemical data suggest some important quantitative differences: the loess soils are dominated by quartz, feldspars and smectite minerals, inherited from the parent material, whereas the parent materials of the typical soils of the Ardennes contain higher amounts of weatherable primary minerals, micas and trioctahedral chlorite, and also more kaolinite. The composition of the loess is different in Central and High Belgium, the latter having more feldspars and kaolinite.

(2) The mineralogical evolution in all soils is characterized by:

- a chemical congruent weathering of amphiboles present in the silt fraction of some soils;
- a physical breakdown of silt-size mica and especially silt-size chlorite in the top horizons, resulting in an absolute accumulation of these minerals in the clay fraction;
- a chemical incongruent weathering or transformation of mica and chlorite in the clay fraction, forming vermiculitic and smectitic structures with variable basal spacing. This incongruent weathering is most expressed in soils with originally more mica and particularly more chlorite.

(3) The formation of the dominant diagnostic horizons is directly related to the mineralogical composition: the loess soils, with easily translocated smectite in the parent material, have a well-developed argillic horizon. The typical soils of the Ardennes with more weatherable minerals, releasing high amounts of Fe and Al, have developed a cambic horizon with a stable crumb structure.

(4) The loess soils from Central Belgium, resting at shallow depth on glauconiferous Tertiary deposits have this mineral in both sand- and clay fractions. Sand-size glauconite can clearly be observed in the field and under the microscope, but clay-size glauconite can only be recognized by its solubility and related high amounts of K^+ extracted in HCl 1N. The higher amounts present in the Bt horizons, compared to the overlying A horizons, are probably the result of the higher mobility of clay-size untransformed glauconite.

(5) The homogeneity of the typical soils of the Ardennes can be approached through the consistency in the chemical composition. In this way, a decrease of the ratios of Si on the other cations is very often established in profiles on slopes and is characteristic for soils having solifluction material mixed in the surface horizons.

(6) Loess contamination in the soils on the highest plateaus of the Ardennes is negligible because the finest fraction of the loess, mainly smectite, is not present in clearly detectable amounts. In the top horizons, smectites either are absent or form only very small amounts, and the presence of these minerals can be explained by a transformation process of micas and trioctahedral chlorite.

(7) The presence of the crystalline FeOOH minerals, goethite and lepidocrocite, gives some indications on the relative age of the deposits.

- The presence of these minerals in the deepest horizon of the profile in Grand-Leez and in the loess of High Belgium differentiates this material from the loess of Central Belgium, and suggests that the underlying loess of Grand-Leez and the loess of High Belgium are of the same age but older than the loess of Central Belgium.
- The absence of these minerals in the soils on phyllites indicates that these soils are recent, without indications of an older weathering stage.
- The soils on weathering loam have been in place for a very long period; goethite and lepidocrocite had been formed throughout the profile, but in recent time, they have been changed into amorphous or organo-mineral compounds in the top horizons.
- In the soils on solifluction, the soliflucted material is composed of old weathered material containing goethite and lepidocrocite; the period elapsed since its deposition has been too short to destroy the crystalline Fe minerals.

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