

## Characterisation of soils with mollic horizon formed over limestone in a humid temperate climate (Galicia, NW Spain)

### Caracterización de suelos con horizonte mólico formado sobre calizas en clima templado húmedo (Galicia, NW España)

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#### ABSTRACT

Soils with a mollic horizon lying directly over limestone were characterized physicochemically, mineralogically and micromorphologically. The development of these soils involves dissolution of limestone and leaching of the released calcium carbonate under favourable climatic and topographic conditions, the incorporation of insoluble residues (chiefly by inheritance rather than transformation), and the action of efficient humification mechanism. They are classified as *Lithic Haprendolls* by Soil Taxonomy (1998) and as *Rendzic Leptosols* by the FAO classification (1998).

**Key words:** Mollic horizon, soils over limestone, mountainous areas, NW Spain.

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## INTRODUCTION

Limestones are found in eastern Galicia together with schists, slates and quartzites. Differences in the resistance of these metamorphic materials to erosion have given rise to notable variations in relief. The hard limestones originated a landscape with steep slopes and significant lateral transport phenomena which hinder development of soils. For this reason, the soils predominating on hilltops and the steeper slopes of limestone areas are minimally differentiated (TABOADA & SILVA, 1997, 1999). In this work we investigated the factor involved in the first stage of their development, represented by soils with only an A horizon formed directly over the limestone.

## LOCALIZATION AND MORPHOLOGICAL CHARACTERISTICS

The soils studied are located in mountainous areas of the Lugo province (north-west Spain) at altitudes between 750 and 1230 m. Three representative profiles were selected. Profiles 1 and 3 are formed over limestones of the Vegadeo formation,

which are intercalated with slates and dolomites bearing iron minerals. Profile 2 has developed over limestones of the Candana formation, which consist of limestones and marble dolomites (IGME 1980, 1981). All three profiles are located on class 5 or 6 slopes. The predominant vegetation consist of *Quercus rotundifolia* woods with undergrowth composed grasses, *Crataegus* and *Lithospermum*. The climate is humid temperate, with annual precipitation ranging between 1678 mm and 2044 mm (much of it as snow) and an annual mean temperature of about 8°C (range 0.7-15.7°C). The soils are well drained (class 4), with a high degree of infiltration (more than 1 200 mm annually). The soil moisture regime is udic and their temperature regime mesic.

These soils are morphologically very simple (Table 1) consisting only of A horizons 15–25 cm thick which are dark in colour (chromas of 3 or less) and have a well-developed fine crumb structure and predominantly silt loam texture. The presence of schist, slate and quartzite gravels indicates a certain colluvial character, which is not unexpected for these hillside soils.

P	Hor.	Depth (cm)	Colour		Texture	Structure
			moist	dry		
1	Ah1	0–15	5YR3/3	7.5YR4/4	stl	fine crumb
	Ah2	15–25	5YR3/3	7.5YR4/4	stl	fine crumb
2	Ah1	0–8	10YR2/1	10YR3/2	stl	fine crumb
	Ah2	8–16	10YR2/1	10YR3/1	stl	fine crumb
3	A	0–15	10YR3/2	10YR4/2	stcl	fine crumb

stl: Silt loam; stcl: Silty clay loam.

Other common characteristics: Gravels of limestone, schist, slate and quartzite. Abundant roots. Lightly calcareous. Clear boundary with limestone.

**Table 1. General characteristics of the three profiles.**

## MATERIALS AND METHODS

### General analyses of the profiles

Texture, organic matter, total N, pH (water and KCl) and equivalent  $\text{CaCO}_3$  were determined as per GUITIÁN & CARBALLAS (1976). CEC and exchangeable bases with  $\text{NH}_4\text{OAc}$  (pH 7), KCl-extractable Al as per INVESTIGACIÓN DE SUELOS (1973). Citrate/dithionite-extractable Fe and Al as per HOLMGREN (1967). Ammonium oxalate extractable Fe and Al as per McKEAGUE & DAY (1966). Sodium pyrophosphate extractable Fe and Al as per BASCOMB (1968).

### Micromorphological and mineralogical analyses

Clay mineralogy was examined by X-Ray Diffraction (XRD) of randomly oriented material (with or without gels) and of oriented aggregates. All samples were subjected to Mg saturation, ethylene glycol solvation and calcination at  $550^\circ\text{C}$ , and some to K saturation and heating at  $110^\circ\text{C}$  or  $500^\circ\text{C}$  for 2h. The sand fraction between 50 and 400  $\mu\text{m}$  was examined under the microscope, and some components of the sand fraction were also examined by X-Ray Diffraction.

Thin sections of soil (obtained following impregnation with a polyester resin) are described following the nomenclature of BULLOCK et al. (1985).

Soils were classified as per SOIL TAXONOMY (1998) and FAO (1998).

## RESULTS AND DISCUSSION

### Chemical properties

The soils studied contain a considerable amount of organic matter which, judging by its low C/N ratio (around 10), is well degraded (Table 2). Soils pH is slightly above neutral in water and about 6.5 in KCl. Though low in carbonates (equivalent  $\text{CaCO}_3$ , <1%), their exchange complex is kept saturated (principally by calcium) due to the proximity of the underlying limestone, which ensures the replacement of calcium ions lost through leaching. The CEC is quite high, in keeping with the high organic colloids content (Table 2). Extractable Al is much less than extractable Fe. The small amount of  $\text{Fe}_2\text{O}_3$  (o) as compared to  $\text{Fe}_2\text{O}_3$  (d), and its similarity to  $\text{Fe}_2\text{O}_3$  (p), indicates a predominance of crystalline iron compounds and low non-crystalline Fe content.

P.	Hor.	Clay %	Silt %	Sand %	pH		O.M. %	N %	C/N	CaCO <sub>3</sub> eq.%
					H <sub>2</sub> O	KCl				
1	Ah1	20	58	22	7.1	6.2	9.78	0.52	10	0.3
	Ah2	22	57	21	7.4	6.4	3.68	0.52	4	0.4
2	Ah1	18	61	21	7.2	6.5	7.45	0.52	8	0.4
	Ah2	24	61	15	7.5	7.1	4.43	0.43	5	0.9
3	A	28	54	18	7.3	6.4	12.11	0.70	10	0.4
Exchange properties (cmol. kg <sup>-1</sup> )										
P.	Hor.	Ca	Mg	Na	K	S	CEC	V%		
1	Ah1	19.3	3.8	0.06	0.18	23.3	24.4	95		
	Ah2	17.4	3.3	0.04	0.08	20.8	21.7	96		
2	Ah1	21.9	0.8	0.69	0.12	23.5	23.5	100		
	Ah2	22.9	0.6	0.09	0.05	23.6	23.8	99		
3	A	27.3	2.4	0.06	0.13	29.9	30.0	10		
Analyses by chemical extraction techniques (%)										
P.	Hor.	Citrate-dithionite (d)		Ammonium-oxalate (o)		Pyrophosphate (p)		Feo/Fed		
		Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>			
1	Ah1	5.53	0.53	0.93	0.85	0.10	0.23	0.16		
	Ah2	5.89	0.53	0.93	0.85	0.09	0.09	0.15		
2	Ah1	3.56	0.21	0.82	0.85	0.04	0.15	0.22		
	Ah2	3.75	0.28	0.86	1.14	0.03	0.13	0.22		
3	A	3.03	0.21	0.79	0.38	0.14	0.19	0.25		

**Table 2. Physico and chemical properties.**

## Mineralogical properties

### *Sand fraction*

The mineralogy of the sand fraction is showed in figure 1. In all three soils studied, the sand fraction is dominated by primary minerals, especially light minerals such as quartz and feldspars (85–95%). The presence of tourmaline inclusions in some feldspar grains in profile 2, and their absence from the underlying limestone, corroborates the morphological evidence of a non-limestone lithological component. Among the carbona-

tes, the dolomite (identified by staining with alizarine) predominates in the subhorizon Ah1 of profile 1. Small quantities of micas also appear, as do small quantities of micaceous schist or slate-like fragments formed of small laminae bound by a ferruginous cement.

Among the dense minerals of the sand fraction, the most abundant in profiles 1 and 3 are magnetite, goethite and hematite, and those of profile 2 feldspars with tourmaline inclusions, followed by hematite and magnetite. Bright red hematite and brownish-yellow goethite grains were

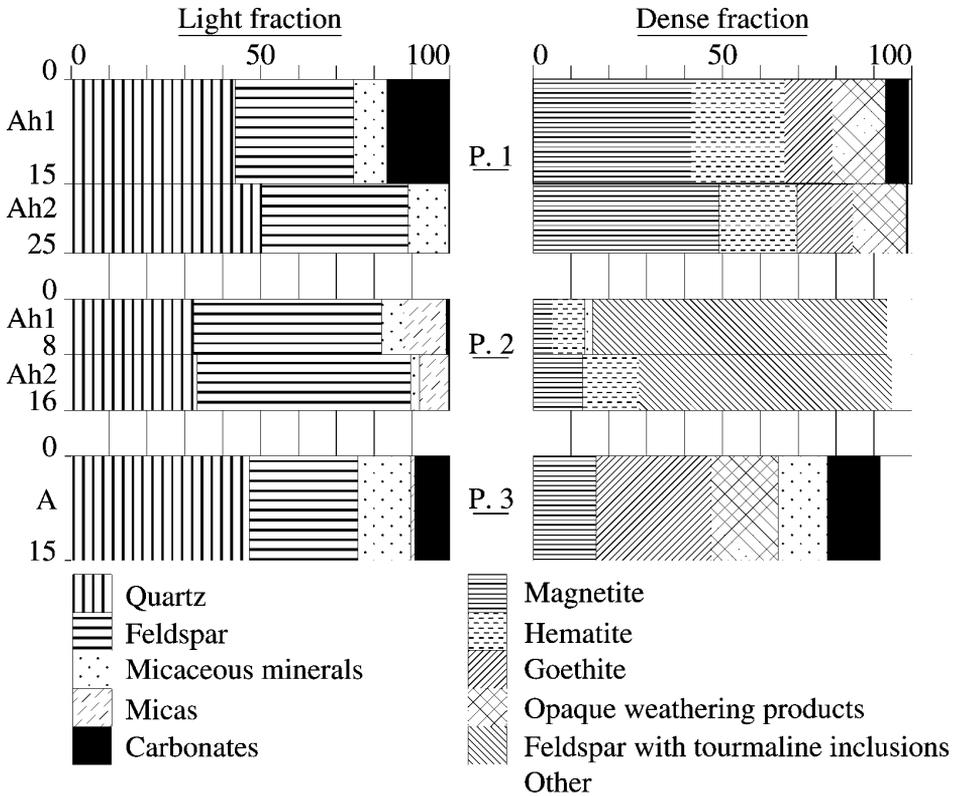


Fig. 1. Sand fraction mineralogy.

counted under the microscope after X-ray diffraction studies had confirmed the correspondence between grain colour and the nature of the oxide. These iron minerals are assumed to have been inherited from underlying limestones, in which they are common (IGME 1980, 1981, TABOADA & SILVA, 1995).

*Clay fraction*

The clay fraction likewise reflects the poor mineralogical evolution of these soils, the principal components being 2:1 minerals (Table 3). Illite is the dominant mineral in profiles 2 and 3, where it is

accompanied by small quantities of vermiculite, chlorite and kaolinite; traces of feldspars and hematite are also found in profile 2, and traces of quartz, feldspars and goethite in profile 3. In profile 1 the major component is vermiculite, which is accompanied by illite and traces of quartz, feldspars and goethite.

The XRD behaviour of the vermiculite of profile 1 differs from that of the vermiculites of most other Galician soils, which have been formed over crystalline acid rocks. Saturation with potassium caused total collapse of the 14 Å peak and a corresponding increase in the 10 Å peak (in the other profiles the collapse was no

Profile	Horizon	Minerals*
1	Ah1	V >> I (K, Q, F, G)
Ah2	V >> I (G)	
2	Ah1	I >>> V (K, Ch, F, H)
Ah2	I (V, K, F)	
3	A	I >>> V (K, Ch, Q, F, G)

\* Ordered by relative abundance. Between parenthesis traces.  
V: vermiculite; I: illite; K: kaolinite; Ch: chlorite; Q: quartz;  
F: feldspars; G: goethite; H: hematite.

**Table 3. Clay mineralogical composition.**

total due to the presence of some chlorite). The aluminium hydroxy vermiculites of Al-rich clay fractions normally require high temperatures or prior treatment with oxalate or citrate in order to shift the 14 Å peak to 10 Å (MACÍAS et al., 1982). The low aluminium content of these soils (Table 2) and X-ray diffraction behaviour their vermiculites, indicate that the inter-layer of the latter consists of magnesium and/or calcium (FOSTER, 1963). These vermiculite are degradation products of the illite inherited from the underlying limestone and from the adventitious schist or slates; in no case was vermiculite found in the rock itself.

With respect to the origin of the large quantities of iron minerals found in the clays of these soils, the presence of the goethite may be due both to neof ormation (since goethite is the most stable iron oxide in humid temperate soils) and to microdivision of coarse grains derived from the underlying rock. The presence of the hematite in profile 2 must be due exclusively to the latter mechanism, since a) the characteristics of this soil would appear to rule out its preferential neof ormation with

respect to goethite, and b) its presence in the clay can be related to the higher hematite content of the sand fraction.

### Micromorphological properties

Al three A horizons studied are very similar micromorphologically. They exhibit a complex microstructure formed by spongy and crumb aggregates which creates a void structure consisting mainly of compound packing voids, vughs, channels and chambers (porosity 28–45%). The ground mass shows a single-spaced porphyric *c/f* related distribution, with some enaulic regions in profile 3. The b-fabric is undifferentiated, with some crystallitic regions in profile 2 as a consequence of the presence of very small particles of mica and calcite. Fine mineral components predominate over coarse. The latter consist of fragments of limestone, schist, quartzite and slate, and of grains of simple minerals (feldspars, quartz, micas and iron oxides with various degrees of hydration). The observation of feldspars with tourmaline inclusions in profile 2 corroborates the sand fraction findings.

The fine material consists of dark brown humic clay.

Plant residues are few and their degree of transformation increase with depth. Fungal sporangia were found in profile 3.

Pedofeatures include abundant spherical and cylindrical excrements distributed in groups (some intact and other aged) and ferrous nodules of various types. The latter are chiefly hematite, as is shown by their red colour under oblique light, although some black nodules indicate the possible presence of manganese.

### Genesis and classification

The principal factors limiting the development of these soils are the hardness and degree of recrystallisation of the underlying limestones (which impedes their alteration); and their location on steeply sloping hillsides, which favours the transport and mixing of materials observed in the morphological, micromorphological and mineralogical studies. The genesis of these soils involves moderate weathering leading to coexistence of primary minerals in the sand fraction, the loss of carbonates from the profile and the net accumulation of well humified organic matter.

With respect to this latter process, it must be emphasised that although these soils exist in conditions that do not favour the decomposition of organic matter (a cold, humid climate with 4 months of temperatures, depressing metabolism), few undecomposed organic residues were found in the micromorphological study. Interaction between organic and mineral

components must have been contributed to by the intense biological activity evidenced by the abundance of excrements and large microbial population (ACEA & CARBALLAS, 1986). Well-balanced mineralisation of nitrogen is attributable to the abundance of ammonifying, nitrifying and denitrifying microorganisms, while the satisfactory soil C/N ratio reflects the activity by aerobic and anaerobic nitrogen fixers (C/N ratio correlates well with microbial activity in these soils; ACEA & CARBALLAS, 1990).

The fundamental role in the humification of these soils is attributed to the calcium made available by dissolution of the limestone. Although the abundant precipitation causes severe leaching of bicarbonate from the soil (which is aided by the texture, shallowness and topography of these soils), it is also effective in solubilizing the  $\text{CaCO}_3$  of the nearby bedrock and of the limestone gravel fragments present in the profile, so that Ca content is kept high. It is significant that in spite of the abundance of iron minerals there is little complexation of organic matter by iron, perhaps because these minerals are largely crystalline and located in the coarse fractions. These facts, together with the soil pH slightly above neutral, the nearly saturated exchange complex and the absence of active limestone, identify the humus as a calcic mull in evolution towards eutrophic forest mull (DUCHAUFOR, 1975).

In conclusion, fundamental pedogenetic processes in these incipient soils are moderate weathering, decarbonation and humification. According to Soil Taxonomy (1998) they are *Lithic Haprendolls* due to

their udic hydric regime and their mollic epipedon less than 50 cm deep lying directly on limestones bedrock. According

FAO (1998) classification *Rendzic Leptosols* on account of their contact with bedrock within 30 cm of the surface.

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