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Genesis of an atypical Podzol in the Iberian Range: micromorphological characterization

Génesis de un Podzol atípico en el Sistema Ibérico: caracterización micromorfológica
Génese de um Podzol atípico na Cordilheira Ibérica: caracterização micromorfológica

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ABSTRACT

A podzol has been described in the Iberian Range (Moncayo Natural Park), which may represent the southernmost example in Europe. The fact that it occurs at the podzol distribution limit makes its morphology atypical. The aim of this work is to identify the components and formation processes of the soil, and to determine if the processes are active or paleo-processes by a micromorphological approach. The study podzol is located in the top of a northern hillside (30% of slope), at 1600 m altitude on quartzitic sandstones, under Scots pine (*Pinus sylvestris*) with an udic moisture regime and a frigid temperature regime. We found opaque, orthic iron oxide nodules at the base of the profile (Bhs1), which is related to a current oxidation-reduction process; silt caps are also observed on the coarse elements, pedofeatures evidencing the cryoturbation process, probably also current processes. In the Bhs2 horizon, coatings and micro-laminated clay infillings are identified that are interspersed with fine silts in the holes. Many of these coatings are fragmented and mixed with the basal mass of the soil, indicating that they are paleofeature, possibly prior to the current podzolization.

RESUMEN

*En el Sistema Ibérico (Parque Natural del Moncayo) han sido descritos Podzols, que se encuentran entre los más meridionales de Europa. El hecho de estar en su límite de distribución hace que su morfología sea atípica. El objetivo de este trabajo es identificar los componentes y procesos de formación del suelo, y determinar si los procesos son activos o paleo-procesos, mediante un enfoque micromorfológico. El Podzol de estudio está situado en la cima de una ladera septentrional (30% de pendiente), a 1600 m de altitud sobre areniscas cuarcíticas, bajo pino silvestre (*Pinus sylvestris*) con un régimen de humedad údico y un régimen de temperatura frígido. Se encuentran nódulos opacos, órticos, de óxidos de hierro en la base del perfil (horizonte Bhs1), lo que está relacionado con un proceso de óxido-reducción actual; también se observan casquetes o cappings de limo en los elementos gruesos, edaforrasgo que evidencia el proceso de crioturbación, probablemente también actual. En el horizonte Bhs2 se identifican revestimientos y rellenos de arcilla microlaminada que se intercalan con limos finos en los poros. Muchos de estos revestimientos están fragmentados y mezclados con la masa basal del suelo, lo que indica que son paleoprocesos, posiblemente anteriores a la podzolización actual.*

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RESUMO

*Na Cordilheira Ibérica (Parque Natural do Moncayo) foi descrito um Podzol, o qual pode representar o exemplo mais meridional da Europa. O facto de estar localizado no limite de distribuição dos Podzóis torna a sua morfologia atípica. O objetivo deste trabalho é identificar os componentes e os processos de formação do solo, e determinar se estes são processos ativos ou paleo-processos através de uma abordagem micromorfológica. O podzol estudado está localizado no topo de uma encosta norte (30% de declive), a 1600 m de altitude sobre arenitos quartzíticos, sob pinheiro escocês (*Pinus sylvestris*) com um regime de humidade údica e um regime de temperatura frígido. Na base do perfil (Bhs1) encontram-se nódulos opacos, órticos, de óxidos de ferro, que estão relacionados com um processo de oxi-redução atual; também se observam capas de limo nos elementos grosseiros, características edafoclimáticas que evidenciam o processo de crioturbação e que serão, provavelmente, também processos atuais. No horizonte Bhs2, identificam-se revestimentos e preenchimentos de argila micro-laminada que se intercalam com limos finos nos poros. Muitos destes revestimentos estão fragmentados e misturados com a massa basal do solo, indicando que são paleo-características, possivelmente anteriores à podzolização atual.*

KEY WORDS
Micromorphology, Aragón (NE Spain), soil, podzolization, argiluviation, cryoturbation.

PALABRAS CLAVE
Micromorfología, Aragón (NE de España), suelo, podzolización, argiluviación, crioturbación.

PALAVRAS-CHAVE
Micromorfologia, Aragão (NE de Espanha), solo, podzolização, argiluviação, crioturbação.

1. Introduction

Podzols represent 3.2% of the world soil cover (IUSS Working Group WRB 2015) and nearly 20% of European soils (Tóth et al. 2008) but they are rare in Spain, where they cover only about 0.1% of its surface (Gómez-Miguel and Badía-Villas 2016). Podzols, Spodosols in Soil Taxonomy System (Soil Survey Staff 2014), are present in NW Spain (Macías and Calvo de Anta 2001; Carballas et al. 2016) and in small and scattered areas in NE Spain such as the Catalan Pyrenees (Bech et al. 1981; Boixadera et al. 2008), the Basque Country (Camps and Aizpurúa 2007) and the Sierra de Urbasa, Navarra (Val Legaz and Íñiguez Herrero 1981a). In some cases, these soils have macro- and micro-morphologic podzolic characteristics but their B horizons do not always meet the spodic horizon diagnostic criteria (Val Legaz and Íñiguez Herrero 1981b). In contrast, other soils meet these criteria but their morphology is peculiar (Badía et al. 2016), probably because they represent the southernmost Podzols in Europe. In order to understand its formation, soil micromorphological investigation can be an excellent option (Stoops et al. 2018). The aim of this work is to characterize the micromorphology of one Podzol, located in the Iberian Range (NE Spain), to identify its components and to determine whether the processes are active or past (paleo-processes).

2. Study Area

The study area is located at the top of a hillside (slope inclination of 30%), in the northern slope of the Moncayo Massif (near San Gaudioso hermitage) at 1600 m above mean sea level (GPS coordinates: 1º 48' 53.59" W 41º 47' 13.72" N). The lithology of the study area consists of Early Triassic quartzitic and micaceous sandstones (IGME 1980). The studied soil develops on a colluvium of these sandstones, mainly quartzofeldspathic, with monocrystalline and polycrystalline quartz grains and K-feldspars (microcline and orthoclase) and mica (Arribas et al. 2007). The average annual rainfall is about 978 mm and the average annual temperature is 6.3 °C; the average annual maximum temperature is 11.9 °C and the minimum is 1.4 °C (Fick and Hijmans 2017). According to the available climatic data, we interpret the moisture regime as udic, and the temperature regime as frigid (Soil Survey Staff 2014). The oaks (*Quercus petraea* and *Quercus pyrenaica*), growing from 900 m to 1200 m, are succeed by beech (*Fagus sylvatica*), from 1200 m to 1600 m above sea level. The latter grove was replaced by Scots pine (*Pinus sylvestris*) due to a reforestation around 1920 (García-Manrique 1960). The understory consists mainly of heathers (*Erica vagans, Erica arborea, Erica cinerea*), hollies (*Ilex aquifolium*), blueberries (*Vaccinum myrtillus*), wavy hair-grass (*Des-champsia flexuosa*) and mosses.

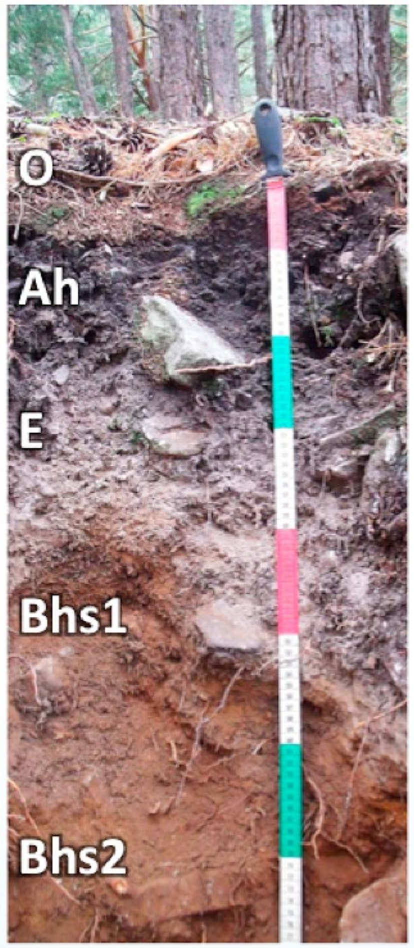

Figure 1. The studied soil profile.

The soil described in the study site has an O-Ah-E-Bhs-C horizon sequence (**Figure 1**) that fulfills the requirements to be classified as Skeletic Umbric Albic Podzol (Loamic) (IUSS Working Group WRB 2015). The O horizon is very well developed, divided in Oe-Oi-Oa horizons, and classified as Humimor (Badía et al. 2018). More details on this Podzol and its factors of formation have been previously described (Badía et al. 2016); a selection of its properties is provided (**Table 1**).

Table 1. Selected properties of the studied soil

Horizon	Depth	pH H_2O	TOC	Alox+½Feox	Base saturation	Textural class	Color
	(cm)	(1:2.5)	(%)	(%)	(%)	(USDA)	(moist)
Ah	0-18	4.1	10.0	0.19	14.3	Sandy clay Loam	10YR 2/1
E	18-30	4.0	1.2	0.09	24.4	Sandy Loam	7.5YR 4/2
Bhs	30-85	5.0	3.1	1.40	12.7	Sandy Loam	7.5YR 3/3
C	85-110	5.1	1.5	0.30	14.0	Sandy Loam	10YR 4/3

Source: Badía et al. (2016).

3. Methods

Oriented topsoil clods were sampled from each soil horizon. Soil clods were placed in containers and transported undisturbed to the laboratory where they were air-dried to a constant weight. A thin section (5 x 13 cm) was obtained from each clod, according to the methods described by Benyarku and Stoops (2005). The thin sections were observed using a petrographic microscope under both plane- (PPL) and cross-polarized light (XPL) and described following the guidelines of Stoops et al. (2018).

Due to the irregular boundary and the thickness of the Bhs horizon, two samples of this horizon were obtained at the top, Bhs1 (24-35 cm) and in the middle, Bhs2 (50-60 cm).

4. Results

The results obtained through the micromorphology of the profile studied are shown in **Table 2**.

Table 2. Micromorphology properties of the studied soil

Horizon	Microstructure	Basal mass	Coarse material	Micromass	Organic matter	Pedofeatures
Ah	Crumb with a very high degree of separation	R c/f 1:2 y RD c/f closed porphyric	Quartz sand	Clay, AOM and fine silt. B-fabric is undifferentiated	Roots and needles, phlobaphenized and carbonized	Channels and excrements
E	Apedial with porosity made of vesicules and channels	R c/f 1:1 y RD c/f single space porphyric	Quartz, biotite, fragments of quartzite and micaceous sandstones	Clay, AOM and fine silt. B-fabric is sericitic crystallitic (micaceous)	Fresh or phlobaphenized root sections	Silt cappings occur on top of coarse fragments (quartzitic sandstone) with voids underlying them
Bhs1	Granular with widely separated aggregates	R g/f 1:2 y RD c/f single space porphyric	Quartz, fragments of quartzite and micaceous sandstones	Clay, AOM, fine silt and Fe oxides. B-fabric is sericitic crystallitic (micaceous)	Fresh or phlobaphenized root sections	Silt cappings occur on top of coarse fragments (quartzitic sandstone) with voids underlying them
Bhs2	Apedial with porosity made of vesicules and channels	R c/f 2:1 y RD c/f closed porphyric	Quartz, fragments of quartzite and micaceous sandstones	Clay, AOM, fine silt and Fe oxides. B-fabric is sericitic crystallitic (micaceous)	Absent	Micro-laminated clay coatings and clay infillings occur in pores, most of them fragmented. Orthic Fe oxides nodules are frequent.

*R, ratio; RD, related distribution; AOM, amorphous organic matter.

The b-fabric of the Ah horizon is undifferentiated due to the abundance of amorphous organic matter, including sections of phlobaphenized pine needles together with charcoal fragments (**Figure 2a**), evidence of past forest burning. In the E horizon (**Figure 2b**), coarse fragments (quartzitic sandstone) have silt cappings above and voids below (**Figure 2d**). The microstructure in Bhs1 horizon is crumb and the b-fabric is sericitic crystallitic (micaceous) (**Figure 2c**). The micromass is redder than in the upper horizons, due to the presence of Fe oxides. In the Bhs2 horizon micro-laminated clay coatings can be observed as well as clay infillings in pores, most of them fragmented (**Figure 2e**). Moreover, orthic Fe oxides nodules are frequent (**Figure 2f**).

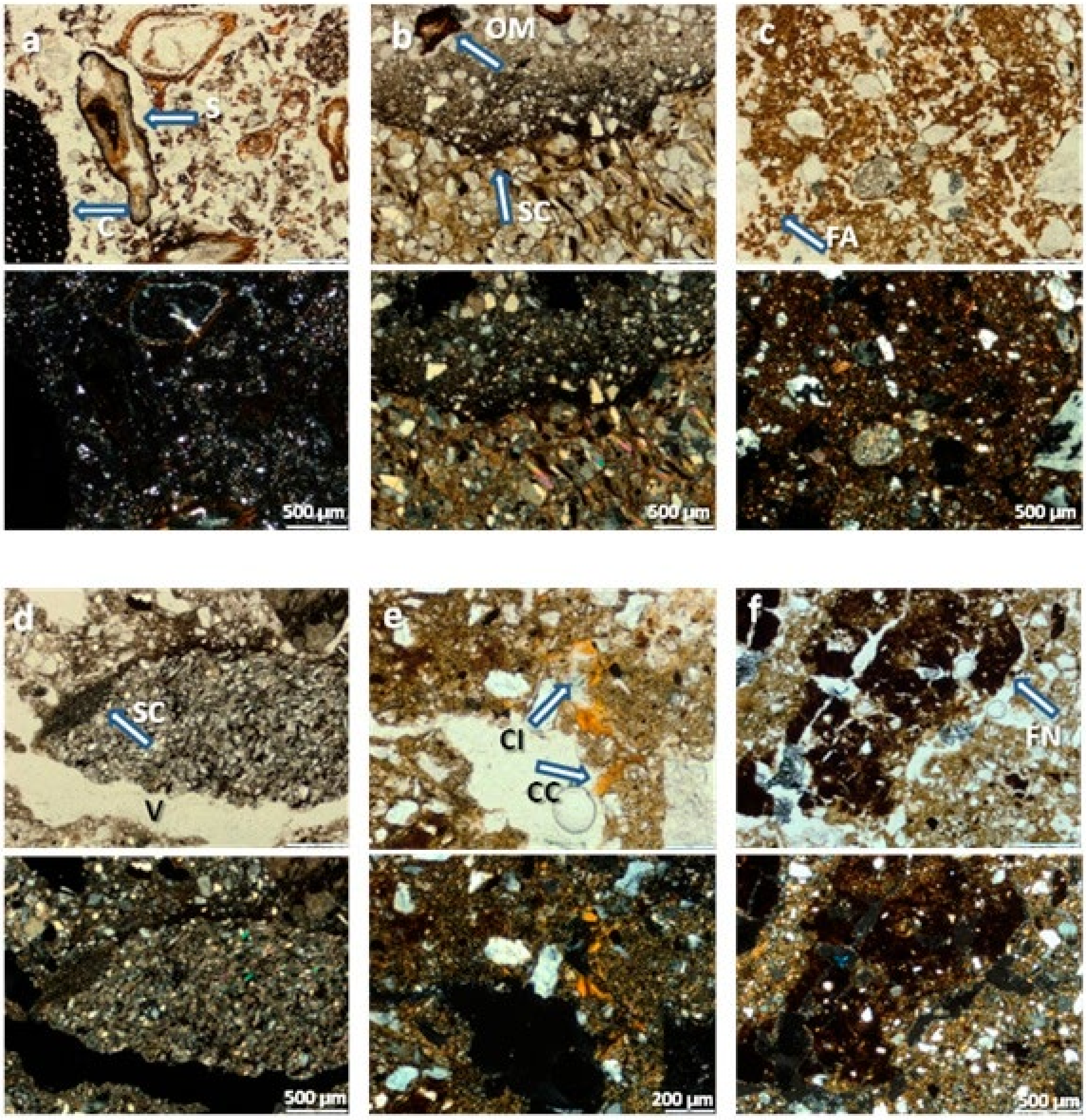

Figure 2. a) Section of phlobaphenized pine needle (S) and charcoal fragments (C) (Ah horizon). b) Silt capping (SC) on a quartzitic sandstone fragment and amorphous organic matter (OM) in the E horizon. c) Intense fauna activity (FA), shown by a granular structure made of faunal droppings and the sericitic-crystallitic b-fabric in the Bhs1 horizon. d) Silt capping (SC) on a coarse particle and void (V) at the bottom in the E horizon. e) Limpid, strongly oriented clay coatings (CC) and micro-laminated clay infilling (CI) in a void in the Bhs2 horizon. f) Fragmented impregnative nodules of iron oxides (and possibly OM) with a dark brown color (FN) in the Bt horizon. PPL (up) and XPL (down).

5. Discussion

The Bhs horizon fulfill the morphological and analytical criteria of spodic horizon and, therefore, the soil can be classified as Podzol (IUSS Working Group WRB 2015) or Spodosol (Soil Survey Staff 2014). Especially striking is the fact that oxalate-extracted Al and Fe contents (Al_{ox}+½Fe_{ox}) is 16 times higher in the Bhs horizon than in the E horizon (1.40% and 0.09% Al_{ox}+½Fe_{ox}, respectively). This pattern is also found in Podzols from the subalpine stage of the Pyrenees (Boixadera et al. 2008). In spite of this, the typical micromorphological characteristics of Podzol (pedofeatures related to the accumulation of colloidal organic matter, Fe and Al in depth (Van Ranst et al. 2018)) are not clearly observed. Instead, micromorphology reveals clay illuviation pedofeatures in the base of Bhs (Bhs2) in spite of the fact that argiluviation and podzolization cannot occur simultaneously since podzolization needs a more acidic pH and the sesquioxides produced during this process do not allow clay movement (Lundström et al. 2000). The observed features related to clay illuviation are mainly fragments of clay coatings, not related to the present-day pore system, therefore the argiluviation has to be interpreted as a paleoprocess, probably occurring before podzolization. For this reason, the Bhs2 horizon is probably a former argic horizon (Bt), nowadays podzolized, which has been later transformed to Bhs (Van Ranst et al. 1980).

Cryoturbation can be responsible for the destruction of clay coatings. Frost action is also responsible for the formation of silt cappings on coarse fragments and voids below them, by ice formation and thawing (Van Vliet-Lanoë and Fox 2018), in both the E and Bhs horizons. This is probably an active process, since the average minimum temperature is -1.7 ºC in the winter months and the average of the minimum temperatures in the coldest month (January) is -4.3 ºC (Martínez del Castillo et al. 2012; Fick and Hijmans 2017).

In the Bhs2 horizon, Fe-nodules are common, opaque, orthic and typic, as results of redox processes. Due to the current udic moisture regime and the water infiltration decrease by the relative clay accumulation in this horizon, these processes are possibly active nowadays, but they should have occurred also during other cold periods by ice melting. Although it is not possible to determine the composition of the nodules with optical microscopy, analytical data show queluviation of OM, Fe and Al in the illuvial Bhs spodic horizon. Replacement of native beech by Scots pine might have caused the soil acidification and also an increase in the polyphenol content that slows down the OM decomposition causing the OM accumulation in the topsoil and forming Fe and Al sesquioxides (Labaz et al. 2014; Leuschner et al. 2013). Due to the relative recent podzolization, it is recognized more from analytical data than from micromorphological observation.

The acidic soil reaction, the horizonation (with a brownish gray horizon Ah, the presence of an E horizon, the increase of OM and Fe and Al oxides in Bhs), as well as the soil-forming factors (Scots pine forest with heathers, quartzitic sandstone, udic regime, etc.) are favourable to Podzol formation.

6. Conclusions

In spite of the fact that the studied profile is clearly classified as a Podzol in the WRB soil system based on its field description and chemical analyses, its micromorphology reveals several features not characteristic of these soils, which point to past processes of clay illuviation. Clear morphologies due to frost action (fragmentation of clay coatings, silt cappings) and redoximorphic features are also observed. These processes are probably active at present given the frigid and udic soil temperature and moisture regimes. In summary, we hypothesize that this profile has been formed by argiluviation processes and subsequent podsolization, which may have occurred by the replacement of the original beech forest by the pine forest and also most likely of climatic conditions.

REFERENCES

- Arribas J, Ochoa M, Mas R, Arribas ME, González-Acebrón L. 2007. Sandstone petrofacies in the northwestern sector of the Iberian Basin. Journal of Iberian Geology 33(2):191-206.

- Badía D, Girona-García A. 2018. Soil humus changes with elevation in Scots pine stands of the Moncayo Massif (NE Spain). Applied Soil Ecology 123:617-621. https://doi.org/10.1016/j.apsoil.2017.07.017.

- Badía D, Ruiz A, Girona-García A, Martí C, Ibarra P, Zufiaurre R. 2016. The influence of elevation on soil properties and forest litter in the Siliceous Moncayo Massif, SW Europe. J Mt Sci. 13:2155-2169. https://doi.org/10.1007/s11629-015-3773-6.

- Bech J, Vallejo VR, Josa R, Fransi A, Fleck I. 1981. Estudio del carácter podsólico de unos suelos ácidos de la alta montaña Andorrana. Anales de Edafología y Agrobiología 40:119-132. [In Spanish].

- Benyarku CA, Stoops G. 2005. Guidelines for preparation of rock and soil thin sections and polished sections. In: Departament de Medio Ambient I Ciències del Sòl, Universitat de Lleida, editor. Quaderns DMACS, 33.

- Boixadera J, Antúnez M, Poch RM. 2008. Soil evolution along a toposequence on glacial and periglacial materials in the Pyrenees range. In: Kapur S, Mermut A, Stoops G, editors. New Trends in Soil Micromorphology. Berlin: Springer-Verlag. p. 39-65. DOI: 10.1007/978-3-540-79134-8_4.

- Camps M, Aizpurua A. 2007. Descripción del perfil Iturrieta B2. In: Abstracts of the XXVI Reunión Nacional de Suelos; 2007 Jun 25-27; Bizkaia: Lurzoru Nazio-Bilra Durango, Spain; p. 93-96 [In Spanish].

- Carballas T, Rodríguez-Rastrero M, Artieda O, Gumuzzio J, Díaz-Raviña M, Martín A. 2016. Soils of the Temperate Humid Zone. In: Gallardo JF, editor. The Soils of Spain. Salamanca, Spain: Springer. p. 49-144. DOI: 10.1007/978-3-319-20541-0.

- Fick SE, Hijmans RJ. 2017. WorldClim 2: new 1 km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37(12):4302-4315.

- García-Manrique E. 1960. Las Comarcas de Borja y Tarazona y el Somontano del Moncayo. Departamento de Geografía Aplicada del Instituto J.S. Elcano (CSIC) y la Institución “Fernando el Católico”. Madrid.

- Gómez-Miguel VD, Badía-Villas D. 2016. Soil Distribution and Classification. In: Gallardo JF, editor. The Soils of Spain. Salamanca, Spain: Springer. p. 11-48. DOI: 10.1007/978-3-319-20541-0.

- IGME (Instituto Geológico y Minero de España). 1980. Mapa Geológico de España 1:50.000. Hoja 352 (Tabuenca). [Internet]. (cited 2020 January 23). Available from: http://info.igme.es/cartografiadigital/geologica/Magna50Hoja.aspx?intranet=false&id=352. [In Spanish].

- IUSS Working Group WRB 2015. Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports Nº 106. Rome: FAO.

- Labaz B, Galka B, Bogacz A, Waroszewski J, Kabala C. 2014. Factors influencing humus forms and forest litter properties in the mid-mountains under temperate climate of southwestern Poland. Geoderma 230-231:265-273.

- Leuschner C, Wulf M, Bäuchler P, Hertel D. 2013. Soil C and nutrient stores under Scots pine afforestations compared to ancient beech forests in the German Pleistocene: The role of tree species and forest history. Forest Ecology and Management 310:405-415. DOI: 10.1016/j.foreco.2013.08.043.

- Lundström US, Van Breemen N, Bai D. 2000. The podzolization process. A review. Geoderma 94:91-107. DOI: 10.1016/S0016-7061(99)00036-1.

- Macías F, Calvo de Anta R. 2001. Los suelos de Galicia. In: Sociedade para Desenvolmento Comarcal de Galicia, editor. Atlas de Galicia. Santiago de Compostela: Xunta de Galicia. p. 173-217. [In Spanish].

- Martínez del Castillo E, Serrano-Notivoli R, Novak K, Longares Aladrén LA, Arrechea E, de Luis Arrillaga M, Saz Sánchez MA. 2012. Cuantificación de los gradientes climáticos altitudinales en la vertiente norte del Macizo del Moncayo a partir de una nueva red de estaciones automáticas en altura. In: Rodríguez Puebla C, Ceballos Barbancho A, González Reviriego N, Morán Tejeda E, Hernández Encinas A, editors. In: Abstracts of the VIII Congreso AEC: Cambio Climático. Extremos e impactos; 2012 Sep 25-28; Salamanca, Spain. p. 519–528. [In Spanish].

- Soil Survey Staff. 2014. Keys to Soil Taxonomy. 12th ed. Washington DC: USDA-NRCS.

- Stoops G, Marcelino V, Mees F. 2018. Interpretation of micromorphological features of soils and regoliths. 2nd ed. Amsterdam: Elsevier. https://doi.org/10.1016/C2014-0-01728-5.

- Tóth G, Montanarella L, Stolbovoy V, Mátém F, Bódis K, Jones A, Panagos P, Van Liedekerke M. 2008. Soils of the European Union. In: European Commission, Joint Research Centre, Institute for Environment and Sustainability, editors. Luxembourg: OPOCE. DOI: 10.2788 / 87029.

- Val Legaz RM, Íñiguez Herrero JI. 1981a. Suelos podsólicos y podzoles de la Sierra de Urbasa. I. Morfología y datos analíticos. Anales de Edafología y Agrobiología 40:381-394. [In Spanish].

- Val Legaz RM, Íñiguez Herrero JI. 1981b. Suelos podsólicos y podzoles de la Sierra de Urbasa. II. Mineralogía de arcillas, micromorfología y génesis. Anales de Edafología y Agrobiología 40:395-410. [In Spanish].

- Van Ranst E, Righi D, De Coninck F, Robin AM, Jamagne M. 1980. Morphology, composition and genesis of argillans and organans in soils. Journal of Microscopy 120:353-361.

- Van Ranst E, Wilson MA, Righi D. 2018. Spodic Materials. In: Stoops G, Marcelino V, Mees F, editors. Interpretation of micromorphological features of soils and regoliths. 2nd ed. Amsterdam: Elsevier. p. 633-662.

- Van Vliet-Lanoë B, Fox CA. 2018. Frost action. In: Stoops G, Marcelino V, Mees F, editors. Interpretation of micromorphological features of soils and regoliths. 2nd ed. Amsterdam: Elsevier. p. 575-603.