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Micromorphological study of the sandy soils in Southern Spain

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INTRODUCTION

The authors are concerned with research into the sandy soils of the Huelva Plain (Southern Spain) [1], mainly using petrographic methods which have been suitably adapted to pedology. In this report the principal ecological factors of the sandy soils in the above-mentioned region are shown and the influence of these factors over the genetic processes and the properties of the said soils are discussed in the light of the results of micromorphological investigation.

The idea that the general ecological characteristics of the region in question should lead to the development of the soils towards a climax formation is left on one side. However, at the same time it is thought that the variations in certain factors of the genesis of the soil must determine edaphic formations which can be related in some way to the first. Therefore, the study of the principal factors in the genesis of the soil and the micromorphology of the various edaphic and geological formations should represent a satisfactory method of finding out the most characteristic pedogenetic processes in the region, the outstanding properties in the representative soils and the relationship between these and the past and present prevailing conditions of the medium.

Although the study of sandy soils in Southern Spain is generally done by granulometric, mineralogical and morphological methods (petrographic methods), this report aims to demonstrate and discuss the results of micromorphological research.

Kubiena's technique has been followed. This entails hardening the soils with CRONOLITA * 1,108, suitably diluted with a special dissolvent, type M*, and adding catalizer C-201 * and cobalt naphtenate at 2%.

Geomorphology. The soils which have been studied are found in the south-east of the Iberian Peninsula, on the Huelva Plain, in a wide area

* Cronopal Plastiform, S. A., Madrid, Spain.

between the rivers Guadiana and Guadalquivir. To the west of this region is the southernmost front of the paleozoic formation, the Sierra Morena, and to the north the Campiña, a terciary of the river Guadalquivir.

According to Rivas and Pérez Mateos [2] the Huelva Plain is composed morphologically of a platform lying at the foot of the Sierra Morena which falls gradually towards the Atlantic and the mouth of the river Guadalquivir. This platform which has a miopliocene base covered with quaternary deposits and terraces, contrasts with the ancient solid wall of the Sierra Morena, but at the same time it is clearly distinguishable from the miopliocene base in these regions where the quaternary erosion and other geological features have broken up or formed the finiterciary sediments.

In respect of the stratigraphy of the zone, it can be said that the miopliocene deposits are composed of blue loam of the Plaseciense, yellow loam and very fine fossiliferous sand with neritic Astiense facies, changing to silicious sands which get progressively coarser towards the surface, ending in a series of coarse sands and even gravels, with ferruginous crusts in some places. These sands and gravels which are situated above the high Pliocene and dominate the fluvialmarine terraces of the quaternary have been considered as Villafranquiense.

The Plio-Villafranquiense platform has been deformed by arches of a huge intraquaternary radius.

Other loose sandy deposits exist on the sandy, gravelly and decarbonatized Plio-Villafranquiense platform. The disposition of these and the Villafranquiense base, as a result of the dynamic geology of the region, have determined definite physiographic and hydrographic areas: beaches, dunes, "corales" lakes, aluvial plains, terraces, etc. In these areas the edaphic formations show certain peculiarities which will be commented on later.

Climate [3]. The temperature of the region is generally moderate: the maximum averages are about 36.5°C in mid August and about 14.3°C in the months of January, February and December. The minimum averages are in the order of 4°C in December, January and mainly February, about 20.5°C in mid August; the very lowest in summer is between 14-15°C and occurs between July and September.

The annual precipitation is in the order of 550 l/m^2 and is fairly uniform throughout the region. Rainfall of more than 50 l/m^2 is found between October and April, and between May and September the region is dry with rainfall lower than 40 l/m^2; there are months (June, July and August) when the precipitation is less than 20 l/m^2.

The annual mean evaporation is in the region of 1,000 to 1,400 mm. As for insolation, in July and August during which months the cloud cover is at its lowest, the amount is almost theoretical, whilst in October and March there is a sharp decline in the number of hours of sun. In

November and January the observed insolation is about 50% of the theoretical insolation, whilst in July and August it is in the order of 85%. During the second ten days of July the sky is completely clear, whilst in the third ten days of March only 12% of the days are clear.

The maximum measured amount of solar radiation is in the first ten days of August (more than 600 cal/cm² per day) and the minimum is in the second ten days of February (125 cal/cm² per day).

To sum up, the region, due to a level topography, does not show great changes in the climate; on the other hand, because of its geographical position, there is a certain influence from the Atlantic. As regards the genesis of the soils, the microclimatic modifications, determined by local hydrological variations are very important because they show clearly in the vegetation.

Vegetation [4]. The transition from clay or silty clay soils in the Campiña, situated in the north of the region, to sandy or silty sandy soils in the Huelva Plain is reflected by the presence of calcifuges vegetations Ulici-Cistion, with *Cistus crispus* L., *Lavandula stoechas* L., *Cistus albidus crispus, Cistus monspeliensis* L., *Cistus salviifolius* L., *Tuberaria guttata* L., etc.

The sabulous flora is characterised in the driest sandy ground by an area planted with cistus (*Halimio-Cistetum bourgaeani*) which contains: *Cistus bourgaeanus* Coss., *Halimium halimifolium* (L.), *Ulex australis* Clem., *Ulex genistoides* Brot, *Lavandula stoechas* L. subsp. *Lusitanica* (Chayt.) *Rozeira, Thymus mastichina* L., *Cytinus hypocistis* L., *Thapsia villosa* L., *Astragalus lusitanicus* Lamk, etc. In the intermediate spaces in this area appear a community of annuals (*Tuberarion guttati*).

Dense zones of *Myrtus communis* L., exist in the lowest and most humid sandy areas and one can also see *Phillyrea angustifolia* L., *Pulicaria odora* (L.) Echb., *Clematis flammula* L., *peregrina* L. var. *longifolia* (Poir.) Rouy, *Anemone palmata* L., *Pistacia lentiscus* L., *Chamaerops humilis* L., etc. On the edge of these depressions *Festuca ampla* Hack which has been noted as being of the Iberian North African species, typical of the mediterranean lusitanian territories, and also *Cistus ladaniferus* L., *C. crispus* L., *C. salviifolius* L., *Rosmarinus officinalis* L., etc.

On the edges of the temporary pools which dry up in summer one can find the following grouping of herbaceous plants which vary according to the humidity: (1) *Tuberarion guttati*, (2) *Agrostion salmanticae* and (3) *aquatic* vegetation with *Ranunculus* subgen. *Batraichium, Echinodorus ranunculoides* (L.) Engelm., *Scirpus maritimus* L., etc.

The group *Halimio-Cistetum bourgaeani* in the dry sandy soils is substituted by a less xerophile community which is related to the atlantic heather of the *Ulicetalia* type.

In the areas where the residual humidity is greater during the summer, one can see a small amount of peat on the surface and *Ulex minor* Roth. var. *lusitanicus* (Webb) *C. Vicioso, Pteridium aquilinum* (L.) Kuhn, *Erica ciliaris* L., etc. are abundant. A second level of drier vegetation can be found on the higher lands. This includes *Erica scoparia* L., *Erica umbellata* L., *Arbutus unedo* L., *Calluna vulgaris* (L.) Hull, *Sarothamnus grandiflorus* (Brot.) Webb, etc. Because of the increased dryness in the soil xerophile association *Halimio-Cistetum bourgaeani* gradually decreases.

The zone of coastal dunes, once it begins to extend away from the beach is characterised by groups: (a) *Loto Amnophiletum*; (b) *Artemisio-Armerietum pungentis*; and (c) *Rhamno Juniperetum macrocarpae* (composed of *Juniperus oxycedrus* L. subsp. *macrocarpa* (Sibth 8 Sm.) Ball., *Juniperus phoenicea* L., *Rhamnus oleoides* L., *Corema album* (L) D. Don, etc. The annual ephemeral species in the undetermined sandy areas which are free from salt are made up of groups of Anthyllido-Malcomion.

The natural arboreal vegetation is quite scarce and composed of *Quercus suber* L., some *Pirus communis* L., subsp. *mariana* (Wk.). *Arbutus unedo* L. (arboreal). *Populus alba* L., and areas of pines and eucalyptus (*P. pinea* L. and E. sp. pl., mainly *rostrata* Schlec.).

RESULTS AND COMMENTARIES

The facts concerning geology, climate and vegetation of the Huelva Plain can be jointly interpreted in an abridged manner in order to study their effect on the genesis and evolution of the soils. In the first place, it must be pointed out that the predominant base is a sandy deposit, both silicious and quaternary, which is very similar in composition and granulometry to that of the beaches and dunes in the region [1]. In turn these deposits are not very different from the sands which form part of the materials of the Villafranquiense of the zone.

From the climatic point of view the region is mainly characterised by a dry prolonged summer period and a rainy season divided in two parts (the beginning of Autumm and the end of Winter). Undoubtedly, this climate must reflect on the evolution of sand-based soils which are influenced by bushy vegetation determined by the said geo-climatic conditions.

The results of micromorphological investigation of the most typical soils in the region can be presented and commented on as follows.

In effect, as Albareda [5] has already pointed out, there are one raw soil and a ranker of dunes near the Andalusian coast. These soils are lacking in organic matter (1.0%), slightly acidic (pH 5.75 to 6.45) and with C/N carbon nitrogen superior to 10. The profile type (A)C and AC, shows in the upper horizon an abundant mineral skeleton of quartzy grains [1] and humus which is notably thicker on the surface and finer [6] in the deeper areas.

It can be said of the dunes nearest the coast that the erosion, eolic sedimentation and climatic conditions only permit the formation of rankerform soils because of the above mentioned plant associations. This contrasts with the evolution of sand based soils in more northerly latitudes, as in Northern Europe [5].

Relatively near to the second and third ranks of dunes, in the area known as Coto Doñana, there are various lagoons (Laguna de Santa Olalla, Laguna del Sopetón, Laguna del Taraje...) which are of great interest in biological research. The vegetation around the lagoons does not only reflect the microclimatic and hydromorphical variations in these areas but also through this one can study the trend of soil evolution.

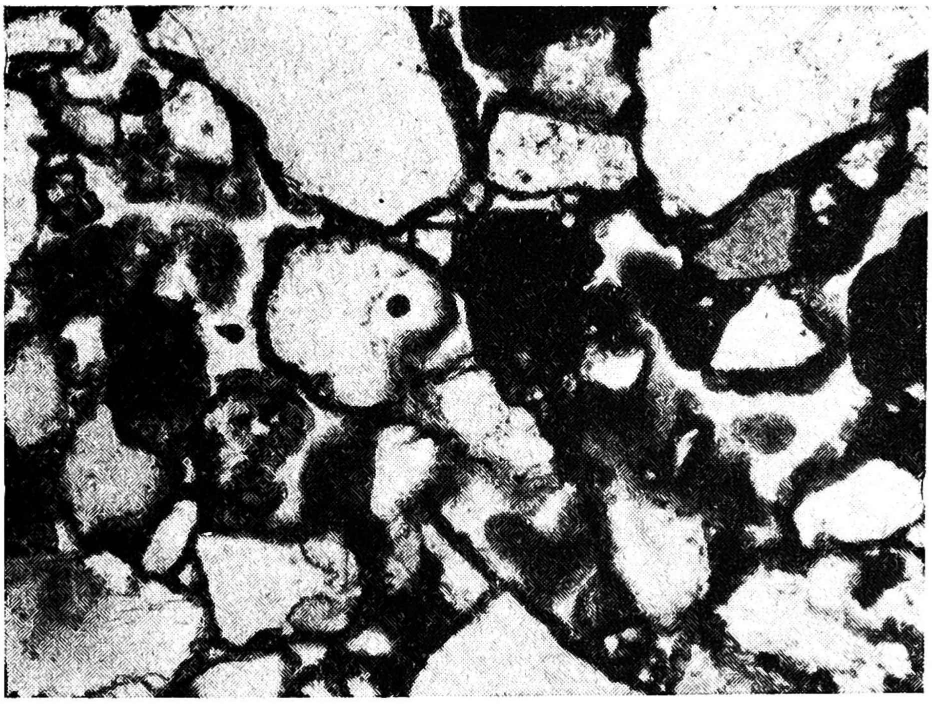

Fig. 1. Villafranquiense sediment: horizon II Bt of brown ranker, at Cartaya (Huelva). Eluviated birefringent plasma between skeleton gains, rubified. Magnif. ×100.

In effect the organic mineral stratum in the soils in this zone has the highest proportion of organic matter (4-7%) whilst pH and the relationship C/N carbon nitrogen, varies relatively less than that of the fore-mentioned rankerform soils.

As is indicated in the study of vegetation [4], there exist in these areas communities which are much less xerophile than those of the association Halimio-Cistetum-bourgaeani in the surrounding areas, which show a certain affinity to the Atlantic heather. The combined effect of microclimate and vegetation is clearly defined in the soils who A horizons, which are either dark coloured (10 YR 2/1) or very dark brownish grey (10 YR 3/1) and fetted with many roots and a certain peat formation, rest on A/C horizons which are brownish grey (10 YR 5/2) occasionally with brownish yellow patches and ferruginous separations of oxide-reduction. In these

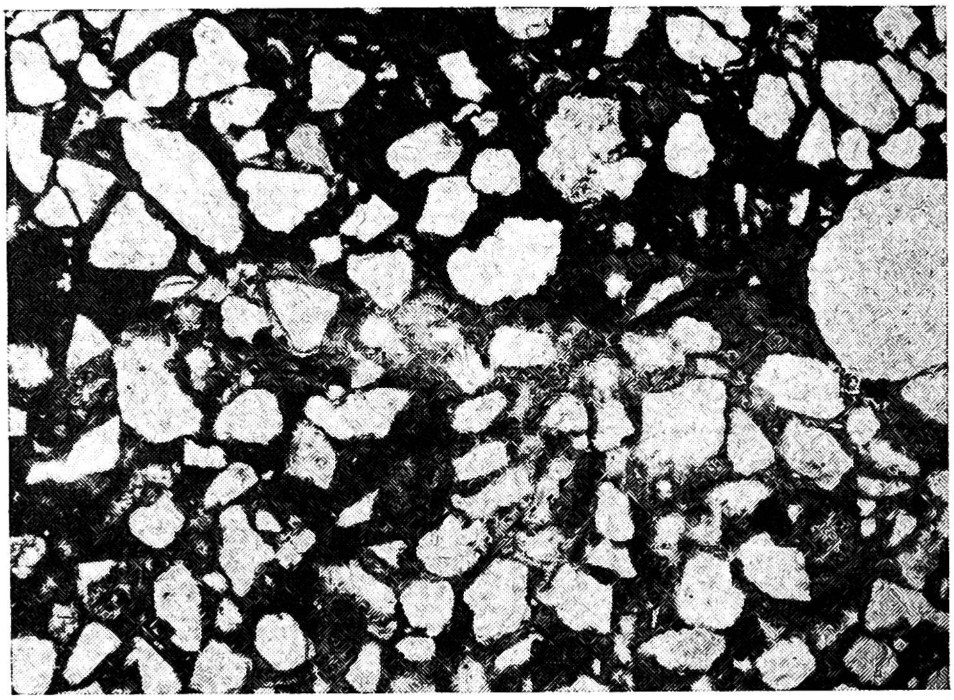

Fig. 2. Villafranquiense sediment: horizon II Bg_2 of eolic sand ranker. Eluviated intergranular plasma with pseudogleyzation. Magnif. ×100.

soils the water table appears at the end of winter, at a depth of approximately one metre; therefore one sees a change between subaquatic and sandy gley soils, with hydromorphic moder, and the ranker on the dry lagoon banks which have a sandy moder.

Micromorphological research reveals the existence of vegetable remains which are only slightly decomposed, if at all, especially the most resistant types which tend to form peat and others in a very advanced state of change. One can also see the debris of animal life which in time becomes predominant and so characterises as moder the resultant humic formation. Because of the high proportion of sand, the structural development has no other micromorphological manifestation than that pro-

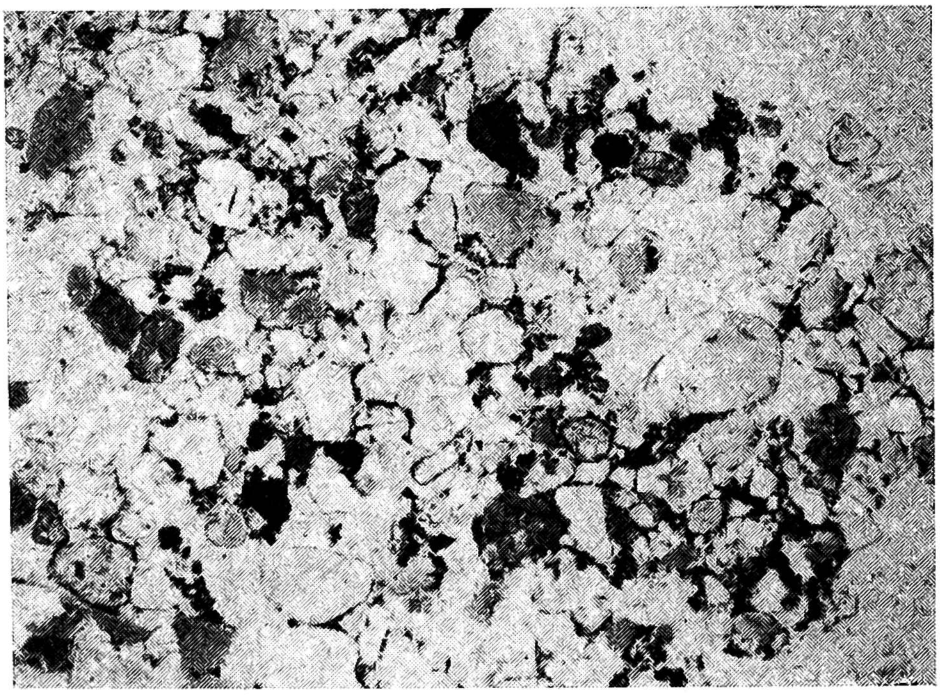

Fig. 3. Dune ranker moder micromorphology. Magnif. ×100.

duced by a dense root network in the plants of the sandy substrata. On a thin slide one notices that there are many empty spaces between the vegetable remains, at various stages of decomposition, and grains of sand (Fig. 4).

The soil of the inland regions, composed of plains of deep sand under dry bushes Halimio-Cistetum bourgaeani, are very similar to the coarse soils and dune ranker: a low proportion of organic matter, slightly acidic pH and humification which leads to a sandy moder. In these zones one can find differences in the soils, more or less sharply defined, in respect of the said dune rankers according to the thickness of the eolic sand layers covering the lower Villafranquiense sediment, which has a clay-sand

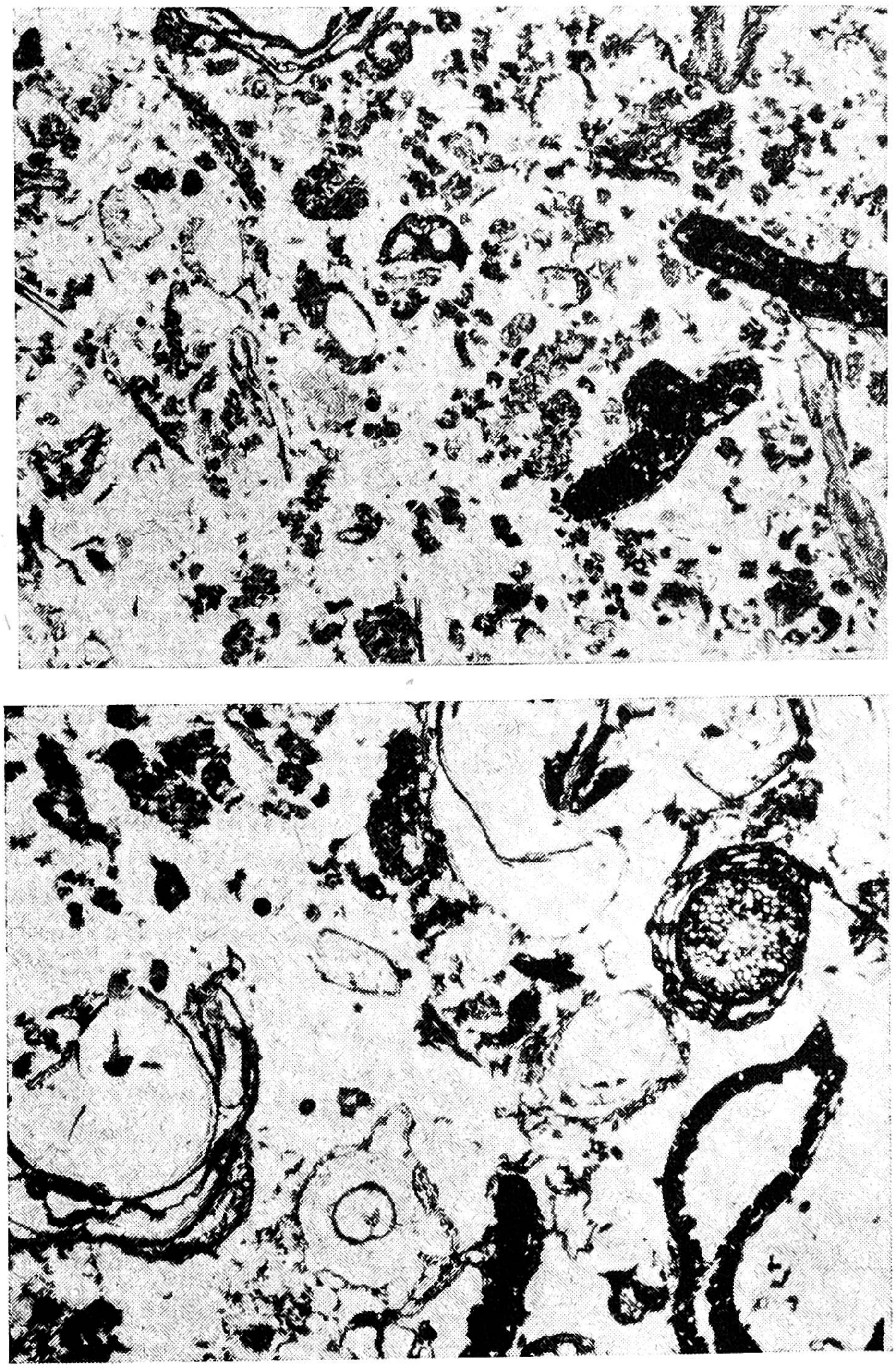

Fig. 4. Detritus of vegetal decomposition and moder under heather and genistea material (ranker A horizon on eolic sands with deep water table). Magnif. ×100.

texture and is compact, variegated and damp. The disposition of these two sediments, which determines the principal morphology of the whole, varies according to the area because of the different geological origins of each one and especially as a result of the processes of sedimentation and erosion which will distinguish an old relief and other newer ones, fundamentally eolic which will partially conceal the first (Fig. 3).

Petrographic investigation, especially micromorphology, has shown that many soils in the region have complex profiles due to the superposition of the above mentioned sediments; some have similar characteristics to these of the pseudogleys, planosols and ferruginous soils with more or less rubefaction; and others of washed sands, slightly acidic, ash coloured, which resemble those of podzols. Although some soils and paleosols with these characteristics have been described in the Mediterranean region, in the research zone the micromorphology of the soil and the outlined ecological factors [2], [3], and [4] show that the present pedogenetic trend is towards the formation of ranker with sandy moder.

Conditions favourable to permeability, the relatively scarse precipitation and the annual mean temperature are factors which have determined the fact that in spite of a relatively damp and even hydromorphic subsoil, the edafic genesis leads to surface formations which are eminently terrestrial and rankerform. However, because of these same factors, phenomena or complex processes take place in the depths: the underlying sediment, which will be mentioned later, is undergoing a change at present time in the area of or on the edge of both horizons which seems analogous to that which was predominant at the end of the terciary or at the beginning of the quaternary during the formation of the joint diluvial estuary of the rivers Guadalete, Guadalquivir, Tinto and Odiel [8].

In effect, whilst one continually proves the trend towards the formation of humus, sandy moder, on the surface, a lithological discontinuity, IIC, should be registered under the sands which constitute horizon C, this discontinuity being in fact analogous to a pseudogley horizon g_2 [9] and could be called $IICg_2$; as g, effects the transition from C to $IICg_2$ or horizon Cg_1.

The outstanding micromorphological characteristic of horizon $IICg_2$ is a porphyroskelic related distribution with an abundance of quartzy sand grains. A yellow plasma of ferric clay fills the intergranular spaces and shows a certain degree of orientation [10]. Similarly, there appear differentiated nodules and ferruginous concretions which are typical of pseudogley. According to Kubiëna's terminology this condition could be called braulehm plasma with pseudogleyzation.

The capacity for diffusion and separation of the iron in the Villafranquiense sediment which is resisted as much in strata $IICg_2$ as at greater depths in the corresponding geological formations, let us suppose that the pliovillafranquiense sedimentation in this area underwent a physicochemical change similar to that of the pseudogleys. Therefore, according to the research which has been completed until now, this change could be said to be characteristic of the sediments of the oldest terraces of the Guadalquivir and of the others which constitute the geological formation which serves as base for the eolic areas of the Huelva Plain.

The pseudogleyzation processes in the sedimentary material culminated in determined areas with others of rubefaction, since the villafranquiense sediments which are free from eolic sands culminate in red paleosols whose exact position in Kubiëna and Aubert-Duchaufour's system, even at the type and group level, are difficult to locate.

In the zones where the outcropping of these rubified sediments occurs there appear red soils of erosion IIBt-IIC, or else rankerform soils A-IIBt-IIC or a brown ranker A-A(B)-IIC developed from recent and less sandy sediments on top of old sands IIC, with or without gravel and coarse sand, which allow this evolution: These considerations are based on micromorphological investigation which clearly shows the existence of: (1) Humus moder-mulliform which tends towards mull in the brown ranker and has a more or less spongelike microstructure on a basic terrified mass, with pores and empty cavities which fill the intergranular spaces and unite the sands and gravels. (2) Rubefaction, with movement of ferrous-clay plasma, in the fine matter which exists in the quartzy grains of the upper Villafranquiense sediment (Fig. 1,2).

FINAL COMMENTS AND CONCLUSIONS

We believe that the results of micromorphological research into the sandy soils of the Huelva Plain give us a more comprehensive knowledge of the present and ancient pedogenesis of the region and of the fundamental properties of these soils, especially when one considers the outlined ecological factors (geology, climate and vegetation) and the commentaries dealing with micromorphology and petrography (mineralogic and granulometric).

The climax soil of the Huelva Plain is undoubtedly a sandy ranker or dune ranker, even when the physiographic word dune cannot be properly applied in the flat zones.

Due to topographic, microclimatic and especially hydromorphical variations there are some soils which are semiterrestrial and aquatic to a greater or smaller degree, representing formations which are strictly dependent on the particular medium. On the other hand the dynamic geology is largely responsible for the genesis of rankerform soils with pseudogleyzation which is more or less deep because of a lithological discontinuity.

Considering the southern brown soil, the climax soil of Southern Spain, those of the Huelva Plain approach this formation when the basic material is not a sediment composed exclusively of sands and when the vegetation corresponds to a mediterranean bushy-wood type.

Finally, the micromorphological method and field studies, incorporating petrographic, sedimentologic and pedologic criteria, indicate that the Villafranquiense sediments show petrographic characteristics which makes it possible to relate them to the oldest material in the terraces of the river Guadalquivir, having contrasted in the one and the other that the physicochemical process in the evolution of the fore-mentioned sediments is analogous to that which characterises pseudogleys. In some areas processes occur later than pseudogleyzation which lead to the formation of red soils and also relict at the present time.

SUMMARY

The main ecological factors of the sandy soils of the "Llano de Huelva" (South Spain) are outlined and the results of the micromorphological study are discussed in order to know the genetic processes and fundamental properties of these soils. Using thin section techniques the morphological characteristics and the dynamics of the recent and old pedological and sedimentary formations are investigated. It is also possible to show the genesis of some compex profiles. The climax soil of this region is a sandy dune ranker with moder humus, but depending on the environment conditions raw soils, brown ranker, pseudogley-ranker and peat soils can be also developed.

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