MICROMORPHOLOGICAL CHARACTERISTICS AND ORIGIN OF SOILS FORMED IN THE UPPER APTENSE PERIOD (MIDDLE CRETACEOUS) IN THE CAZORLA MOUNTAINS, JAEN (SPAIN).

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ABSTRACT

This study describes several paleosols developed in the Upper Aptense period (Middle Cretaceous) in a hot, humid climate. The material occurs between two marine sediments in which fossils have been dated and the environments of formation determined. Located in the Cazorla Mountains (Province of Jaén) in southern Spain, the soils are found on different geological materials under a vegetation coverof repopulated Pinus. Present day climate is Mediterranean, with annual precipitation ranging from 770 to 1347 mm, maximum average daytime temperatures ranging between 15.7° and 26.6° C, and minimum average temperatures between -2.9° and 4.4° C. Among other textural features of interest, the soils are characterized by the presence of iron nodules, the destructive effects of $CaCO_3$ on these nodules, the transformation of hematite into gorthite, and the more recent appearance of illite in the clay fraction, which in all likelihood was formed more recently than the rest of the material studied. Their analytical and morphological characteristics make these soils difficult to classify.

INTRODUCTION

The Cazorla Mountains, located in the province of Jaén (southern Spain), cover an area 70 Km long by 20 Km wide. The terrain is rugged, with sharp changes in slope and altitude. Vegetation consists mainly of repopulated Pinus, and the present day climate is Mediterranean, with annual precipitation ranging between 770 and 1347 mm. Maximum average temperatures vary from 15.5° to 26.6°C and minimum average temperatures from -2.9° to 4.4° C.

As shown in the geological scheme in Figure 1, the Jurassic period strata contain dolomites and oolitic limestones from the Lias and possibly Dogger periods. The ferruginous surface of these rocks is overlain with a level of red clays from the Cretaceous period on which dolomitic sands and dolomites from the base of the Cretaceous period are found.

In the Cazorla Mountains the Cretaceous period begins with a contrasting layer of ferruginous clays, followed by dolomitic sands and brown dolomites at the base of the Lower Cretaceous. In the nearby Del Pozo Mountains, marls are overlain by a discontinous layer of ferruginous clays. Stratigraphic analysis dated this layer as Upper Aptense. The most recent strata contain green marls and dolomitic sands. These ferruginous clays were identified as red paleosols formed in the Aptense and later exposed by weathering (García Hernández, 1978).

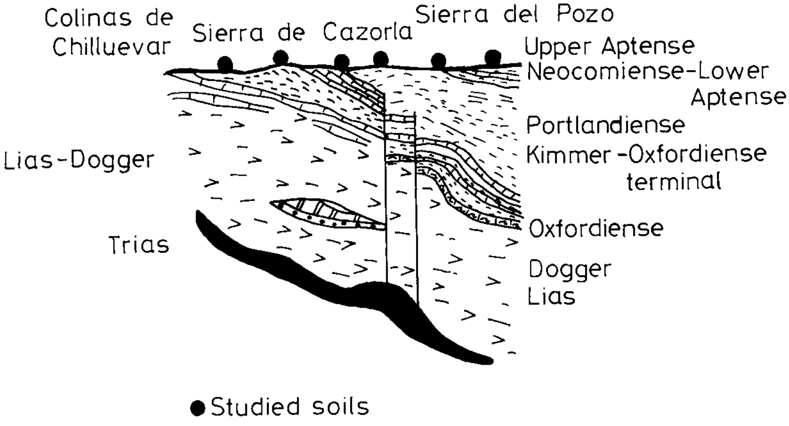


Figure 1. Geological scheme of the Cazorla Mountain area studied (after García Hernández, 1978).

Constituting more than 5 % of the material in the zone known as Cerro de las Albardas, these paleosols are difficult to fit into the FAO (1967) classification or the Soil Taxonomy System of USDA (1975). Although morphological features are those ferralitic soils, the analytical data are contradictory: the C.E.C. of these soils is above that typical of the both oxic horizon and if ferralic properties are taken into account. It therefore seems inappropiate to categorize them as either ferrasols or ferralic cambisols.

MATERIALS

These soils were located on flat areas of calcareous colluvium from conglomerates exposed in numerous outcroppings. Three soil profiles, sampled at Collado de los Perdigones (1), Los Rasos (2) and Collado de los Plomos (3) were studied. The horizon sequence could be relatively clearly distinguished as Ah, Bw, BC and C. All were deep with a sandy loam to clayey loam texture and subangular blocky structure (Figure 2).

RESULTS

Table 1 summarizes the analytical data obtained from the various horizons identified in the three soil profiles. Profile 2 contained relatively large amounts of organic matter. pH was closely correlated with CaCO3 content, which varied considerably, not only between profiles but also, somewhat surprizingly, between horizons within a given profile. High levels of free and total Fe were also found. A breakdown of clay mineralogy yielded 5% illite, 20% kaolinite and

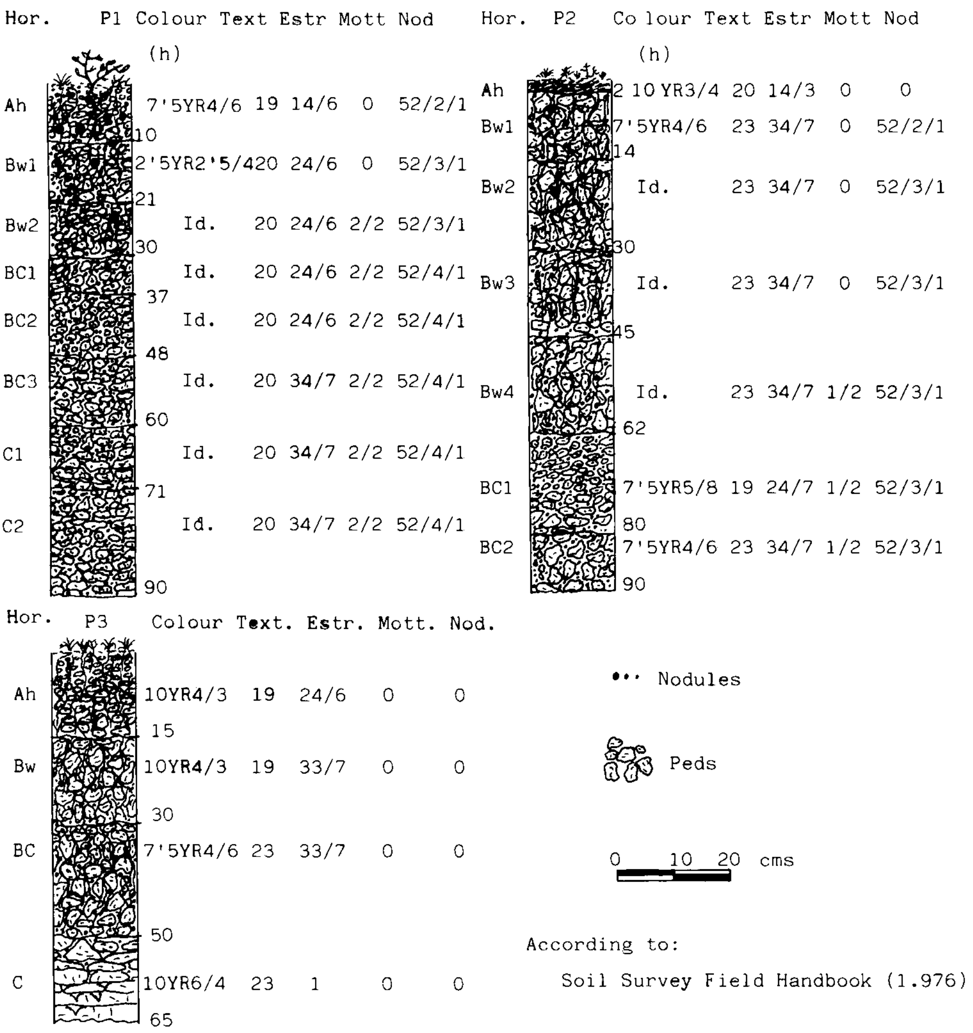


Figure 2. Scheme of the soil profiles from Jaén (Spain) analyzed.

75% Fe and Al oxides. The iron nodules consisted mainly of hematite and goethite with some gibbsite.

MICROMORPHOLOGICAL STUDY

1. Ah horizons

These horizons were usually of moderate geneity (Bullock et al., 1985) with the exception of profile 1, in which the horizons showed low geneity. Microstructure was usually aggregated with subangular blocky aggregates of

TABLE 1

Analytical data of soil profiles from Jaén (Spain)

Hor.	Gravel	Sand	Silt	Clay	CaCO3	Ext. iron as Fe	Total iron as Fe	CEC NH4OAc	pH H2O	Organic Carbon %
	%									
Profile 1										
Ah	22.8	41.3	31.2	26.5	13.4	8.58	11.44	8.80	7.6	1.20
Bw1	26.4	53.6	20.5	26.6	3.0	18.61	34.35	6.82	7.6	0.68
Bw2	32.6	55.7	22.4	21.8	0.3	31.48	34.35	5.72	7.7	0.31
BC1	27.7	59.1	20.9	20.0	0.22	25.50	37.21	5.50	7.6	0.23
BC2	11.1	62.6	19.8	16.7	0.10	18.60	44.98	6.38	7.7	0.25
BC3	10.7	61.8	19.2	18.9	0.10	20.03	35.78	6.60	7.7	0.26
C1	15.2	60.3	20.0	19.6	0.16	21.47	40.07	6.60	7.7	0.18
C2	6.0	61.4	18.4	20.2	0.36	21.47	40.07	6.71	7.7	0.17
Profile 2										
Ah	3.6	28.2	40.7	31.1	0.70	5.46	6.37	25.41	6.9	15.30
Bw1	7.4	29.1	20.5	50.3	0.0	8.58	11.58	15.18	6.9	2.69
Bw2	8.6	26.8	19.1	54.1	0.0	10.02	12.88	15.73	6.9	1.28
Bw3	16.2	32.1	19.8	48.1	6.60	8.58	15.74	15.29	7.4	1.26
Bw4	31.3	35.2	27.8	36.9	27.7	10.79	15.75	10.67	7.8	0.81
BC1	28.5	30.8	35.9	33.2	34.9	8.97	11.44	8.80	7.9	0.53
BC2	19.1	38.0	26.3	35.6	12.8	15.74	21.47	9.57	7.8	0.51
Profile 3										
Ah	8.5	42.4	32.0	25.5	2.86	0.91	1.30	7.26	6.6	2.86
Bw	0.3	40.7	29.2	30.1	0.0	1.04	1.43	5.72	7.4	1.23
BC	7.1	36.5	18.5	45.0	0.0	4.94	5.98	5.39	7.4	0.47
C	3.7	27.6	24.6	47.8	10.2	2.01	2.73	8.36	7.8	0.35

medium size; in some cases microstructure was crumbly. Porosity varied from moderate to high, with compound packing voids, followed in order of frequency by vughs and channels. The c/f ratio was 2 . The soils were poorly sorted, and the related distribution pattern was porphyric single-spaced, while the b-fabric was variable. Stipple-speckled b-fabric was present in all profiles,constituting in some cases the entire b-fabric portion while in other places it was found together with crystallitic or undifferentiated b-fabric.

Coarse mineral material was distributed variably: quartz was abundant in profile 2, common in profile 3 and very scarce in profile 1.

Limestone was found only in profile 1. This mineral was common, sparitic and micritic, and measured more than 200 in diameter.

The opaque minerals, made up hematites, and to a lesser extent goethite, varied from scarce to abundant. Alterations in these layers varied from irregular to pellicular.

Coarse organic material ranged from scarce to abundant and from poorly to well conserved. Reddish or brown in color, the remains were usually radicohists (Bal, 1974) containing excrement.

The fine material was reddish-brown in color, consisting of ferruginous, humiferous or carbonated clay. The clays were always speckled, but differed markedly in anisotropy. Pellets and sometime pigments were noted (Babel, 1985).

Textural pedological features were those identified by Bisdom (1967) as "min" goethitans surrounding hematites, and a few matrans around calcitic and ferruginous nodules, seen in profile 1 only. The other profiles showed no remarkable features.

Depletions were not seen in any profile, while only profile 1 showed crystalline features with calcitic dense infilling, equigranular calcitic nodules, calcitic infilling in ferruginous nodules, etc.

Amorphous pedological features included variable numbers of different sized hematitic and goethitic nodules both with and without inclusions, featuring either an internally concentric or undifferentiated fabric. Impregnations and small oval nodules resulting from the destruction of larger elements were also present.

The few brown and reddish-brown excrements seen were organo-mineral in nature and birefringent, appearing both singly and in groups. They were tentatively identified as mite excrements.

2. Bw horizons

Geneity varied with depth, becoming lower in profile 3 and higher in profile 1.

Microstructure was variable. In profile 1, single pellicular grains tended to become aggregated with increasing depth. In other profiles subangular and angular blocky grains showed a moderate degree of aggregation.

At profile 1, porosity was markedly intergranular, constituted by single packing voids. Profile 2 showed frequent interpedal pores made up of compound packing voids, and small intrapedal spaces constituted by channels. Pores in profile 3 were small in the upper part of horizon Bw, increasing notably with depth.

The c/f ratio was 2 in all profiles, and sorting was variable. The Bw horizon in profile 1 was unsorted, while Bw4 was moderately sorted. In the other profiles all Bw horizons were unsorted.

The related distribution patterns varied considerably. Profile 1 showed a gefuric pattern with zones of chitonic, while profile 2 was porphyric single space. The upper part of profile 3 was closed porphyric, gradually becoming porphyric single spaced in Bw2 and Bw3.

All Bw horizons showed a stipple-speckled b-fabric, with variable amounts of striated and unstriated concentric grains.

Coarse mineral material consisted of the same components in the same proportions as described above for the Ah horizon.

Coarse organic material was scarce, consisting mainly of radicohists in which the cellular structure was conserved in some cases but destroyed in most. Some profiles also contained anthracons.

The fine mineral material was usually brown, with zones of reddish-brown. yellowish-brown or yellowish. It was classified as ferruginous or carbonated clay. Profile 1 was cloudy, while the other two profiles were speckled.

Pellets and pigments made up most of the fine organic material, which was scarce.

Textural pedological features included "min" goethitans, which were frequent in profiles 1 and 2 but uncommon in profile 3. Both laminated and unlaminated forms were seen. Unsorted matrans existing as both coatings and infillings were present but rare.

Crystalline pedological features were represented by hipidiotopic equigranular calcitic coatings and infillings, which were frequent in profile 1, scarce in profile 2 and present in profile 3 only at the lower Bw3 horizons.

Amorphous features included typic and occasionally concentric nucleic nodules of amorphous hematites and goethite, both with and without inclusions. These were abundant in profiles 1 and 2, and scarce in profile 3.

3. BC horizons

These horizons were similar to A and Bw. Profile 1 contained an amorphous material made up of dense connected nodules of different nature and fabric. Concentric nodules were common, but there were also typic, geodic and compound impregnative nodules.

DISCUSSION

The hot, humid climatic conditions predominating in the Cretaceous period together with the fact that the so-called paleoequator was passed in the mesogeo domain, are two fundamental factors to be kept in mind when considering how these soils were formed. Figure 3 shows the conditions when the plain was not reactivated, followed by a wide, shallow platform. Earthy materials did not reach this platform, which was covered with shallow, brackish water made almost fresh by abundant rainfall. That they were rich in life forms is proven by the abundance of fossilized characeous algae.

The sudden appearance of fractures reactivated the plain (Figure 4), and led to the formation of rivers, which through erosion filled the platform with earthy material. It is in this phase when, according to García Hernández (1981), these soils were formed at the points shown in Figure 4. Lutites and clay were deposited farther to the south, while at the zone of formation of these paleosols little earthy material (mainly quartz) was found, as expected. This material was most frequently found as inclusions inside nodules.

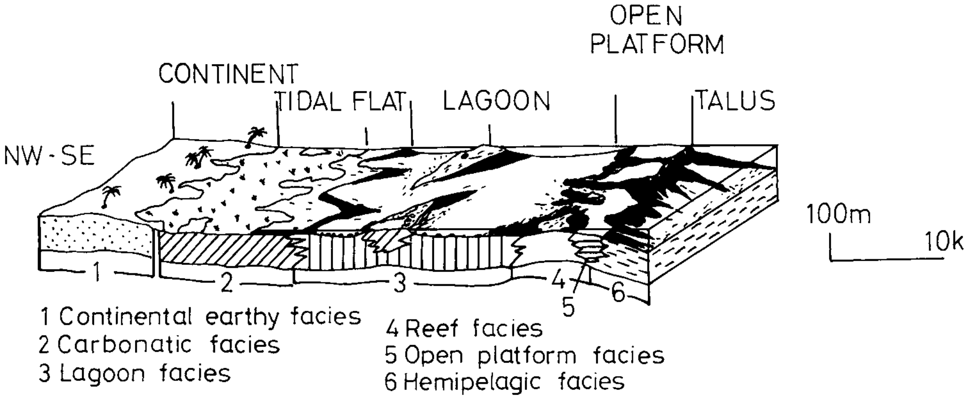


Figure 3. Scheme of the initial phase of formation of soils from Jaén (Spain). (after García Hernàndez, 1981).

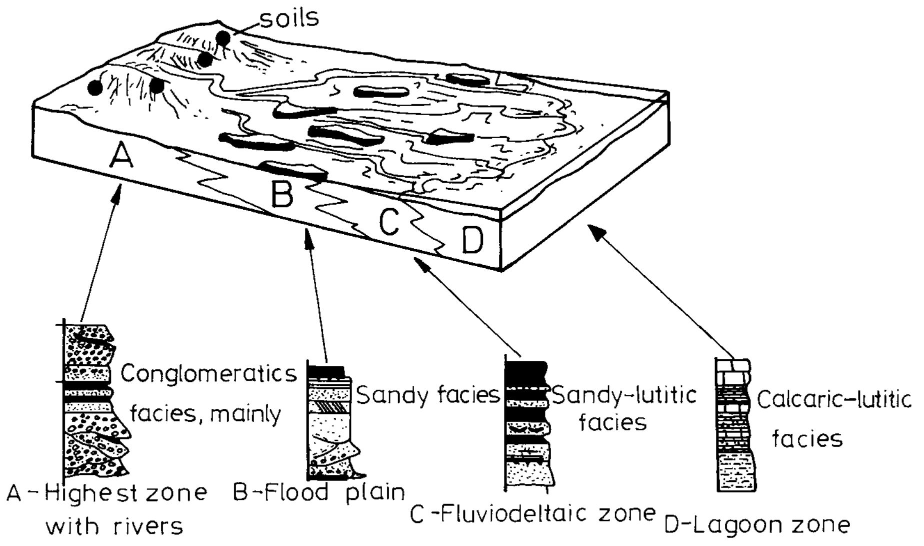
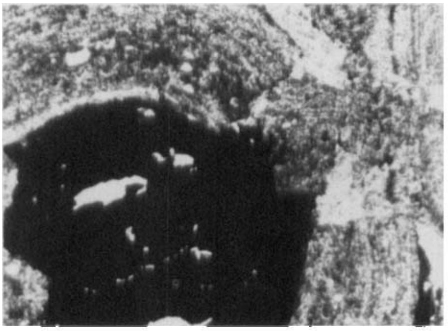


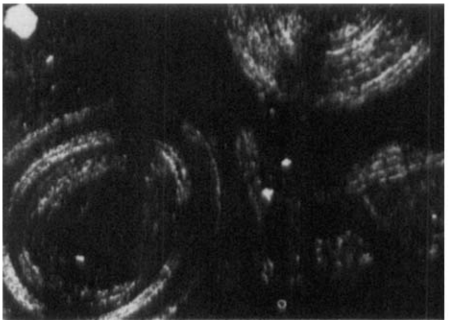
Figure 4. Scheme of the second phase of formation of soils from Jaén (Spain). (after García Hernández, 1978).

How did these paleosols, formed in the Aptense period as noted by García Hernández (1981) and classificable as ferrasols, acquire their present day features?. Rainfall and temperature conditions when the soils were laid down were completely different from modern meteorological and climatological characteristics, making it somewhat surprising that any of the soils original features have survived to present times. The ferrasols formed in the Aptense

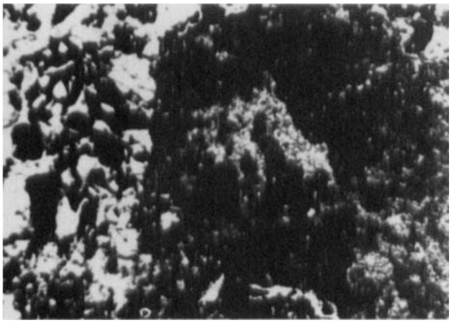


MICROGRAPH 1
Frame length 800 um

MICROGRAPH 2
Frame length 820 um



MICROGRAPH 3
Frame length 805 um



MICROGRAPH 4
Frame length 820 um

MICROGRAPH 1.- "Min" goethitan surrounding a hematite nodule

MICROGRAPH 2.- Calcitic infilling in a ferruginous nodule

MICROGRAPH 3.- Nucleic goethitic nodules

MICROGRAPH 4.- Destruction of ferruginous nodules by calcitic materials were probably made up mostly of hematite, goethite and gibbsite, with kaolinite as the predominant clay mineral. These minerals however could not possibly be formed under current climatological conditions, especially within a calcareous milieu which would prevent the formation of gibbsite and kaolinite. This also seems to be the reason why many of the soils original features have been preserved, e.g. the varying degree of disruption of the ferruginous nodules observed in the present micromorphological analysis.

The presence of illite, albeit in small amounts, is noteworthy, as this mineral must have formed after the Aptense. The transformation of kaolinite is unlikely to have been the source, as this would have involved the improbable transformation of a 1:1 mineral into a 2:1 mineral. Moreover, the absence of I-K interstratified layer also speaks against this mechanism. Illite probably appeared by neoformation. favored considerably by the $CaCO3$ in the soil solution

The high exchange capacity of these soils results partly from the illite fraction, but mostly from the high organic matter content. These features make requeriment 3 of the oxic horizon inapplicable to these soils, hence the difficulty in classifying them into conventional schemes.

The amount of $CaCO3$ varies in the paleosols, at times rising and at times falling as depth increases. Given the estensive presence of limestone throughout the Sierra Cazorla, $CaCO3$ from adjacent areas is likely to have contaminated these profiles. Leaching phenomena were probably responsible for the $CaCO3$ distribution in profiles 2 and 3.

Another feature of interest was the transformation of hematites into mainly pellicular, but also nucleic and occasionally irregular goethite. Such transformation was previously described by Dorronsoro et al. (1979) in soils derived from calcareous rocks, where the transformation sequence pyrite ---- martite ---- hematite was noted in rock, and hematite had become goethite in soils. Finally, our soils contained large numbers of so-called "min" goethitans, which are difficult to fit into the system of Bullock et al. (1985).

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