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MEDITERRANEAN BROWN FOREST SOILS OF THE SIERRA MORENA (SPAIN), THEIR MICROMORPHOLOGY AND PETROGRAPHY[1]

G. PANEQUE and N. BELLINFANTE

Centro de Edafologia y Biologia Aplicada del Cuarto, Sevilla (Spain)[2]

INTRODUCTION

The Sierra Morena, situated in the southwest of Spain north of the Quadalquivir river, is a peneplain renewed by fluvial erosion. It shows a labyrinthic landscape, with a residual relief of lithological and structural origin. In the western region, where this study has been carried out, the highest altitudes do not reach 900 m.

The lithology corresponds to archaic and paleozoic formations. The former is represented by gneiss, mica-schist, crystalline limestones, and chloritic and micaceous slates, and the latter by clayey or micaceous shales and crystalline limestones. There are some plutonic intrusions, mainly formed by granites and syenite in this region, as well as some volcanic ones with diabase, diorite, and serpentine (Macpherson, 1879; Barras de Aragón, 1899; Mingarro Martin, 1961).

The climate of the western Sierra Morena is temperate, with moderate rainfall (750 mm) and generally cloudless skies. The summer is long, dry and very hot, while the other seasons are mild and somewhat humid. The rainfall is highly influenced by the Atlantic Ocean. Winds, generally proceeding from the southwest, move a large amount of clouds, which are held by the mountains of the Sierra Morena after crossing the Guadalquivir Valley. Thus the mountains receive the precipitation. Maximum temperatures rise from about 12°C in January to nearly 35°C at the beginning of August. Minimum temperatures rarely fall below 0°C.

The phytosociology varies with altitude, from the typical species of a Mediterranean sclerophylous forest to those of an Atlantic centro-European caducifolius cold forest. Below 400 m altitude is a climax vegetation of *Oleo-Ceratonion*, defined by the sub-association *Asparageto-Rhamnetum cistetosum*. Between 400–700 m the climax vegetation is *Quercion rotundifoliae*, divided into three sub-associations: *Pireto-Quercetum suberetosum*, *Pireto-Quercetum ilicetosum* and *Pireto-Quercetum faginetosum* (Estudio Agrobiológico de la Provincia de Sevilla, 1962).

The most frequent soil in the Sierra Morena is the Mediterranean brown forest soil, soil climax of this region. This soil is developed mainly

[1] The here treated soils are – according to the U.S.D.A. Soil Classification, 7th approximation (1960) – ochrepts, probably in particular ustochrepts (Ed.).

[2] Director: Prof. Dr. F. González.

on granite and shale, as well as on red soil sediment ("rotlehm"), which represent the three most outstanding varieties of Sierra Morena Mediterranean brown forest soil. The similarity of their humus horizons allows one to classify them as analogous soils according to Pallmann. In particular cases due to topography, lithology, microclimate, vegetation, etc., there are also other soils more or less related to the above: xeroranker, ferritic "Braunerde", relict red soils, etc.

The present work[1] aims to complete and relate the micromorphological study to the main chemical, mechanical and mineralogical determinations of the Mediterranean brown forest soil (Meridional "Braunerde") of the Sierra Morena.

SOIL DESCRIPTION

Profile I

Situation: El Ronquillo, altitude 250 m, mountainous relief, medium slope. Parent material: sienitic granite. Vegetation: climax vegetation *Oleo-Ceratonion*; sub-association *Asparageto-Rhamnetum cistetosum*.

Soil Horizons

0–10 cm: A, very dark grey brown (10YR 3/2), sandy, crumbly to granular, medium organic matter content; good permeability and root penetration;
10–30 cm: (B), dark brown (10YR 4/3), clayey sand, crumbly; medium aeration, somewhat plastic;
30–50 cm: (B)/C, yellowish brown (10YR 5/6), sandy, compact; poor aeration, moist;
50 cm: C_1, decomposed granite.

Micromorphology

A-hor., skeleton of medium sized, somewhat altered, sand grains; the matrix contains brown flocculated iron hydroxides, brownish grey clay-humus complexes, and a little yellow dense plasma. Soil structure shows micro-aggregates and compact fabric, and not much evidence of good biological activity.

(B)-hor., skeleton of small and medium sized, altered grains, which are immersed in the yellow and dense clayey matrix. The latter contains finely flocculated iron hydroxides and possibly brown clay–humus complexes which determine the formation of some aggregates.

(B)/C-hor., skeleton of large grains which have the structure of altered granite; yellowish-brown clayey plasma interposed in the skeleton.

Profile II

Situation: Cala, altitude 530 m, relief flat. Parent material: sienitic granite. Vegetation: climax vegetation *Quercion-Rotundifoliae*; sub-association *Pireto-Quercetum suberetosum*.

[1] This work forms a part of the Doctoral thesis of Mr. Bellinfante, which will be submitted to the Faculty of Science of the University of Seville (Spain).

Soil Horizons

0–40 cm: A, brown (10YR 5/3), loamy sand, crumbly, low organic matter content; good permeability and root penetration;

40–80 cm: (B), yellowish brown (10YR 5/4), sandy, crumbly rather compact; good permeability and penetration;

80 cm: decomposed granite.

Micromorphology

A-hor., skeleton mainly formed by large sand grains, and a few practically unaltered plant remains. The matrix contains flocculated iron hydroxides, scarce non-uniform reddish-yellow and disorientated plasma, and clay–humus complexes. In thin sections soil shows reddish-brown colour and spongy microstructure.

(B)-hor., soil in thin section is similar to the A-hor. in colour, mineral skeleton and matrix. Some irregular microaggregates are also present amongst the sand grains.

C_1-hor., mainly mineral skeleton of medium sized grains; there is a reddish-brown plasma of fluid contexture, somewhat interspersed in the altered granitic.

Profile III

Situation: Cañaveral del León, altitude 580 m, mountainous relief. Parent material: violaceous shales. Vegetation: association climax *Mirteto-Quercetum rotundifolii.*

Soil Horizons

0–10 cm: A/(B), grey-brown (10YR 5/2), sandy-loam, crumbly; some shale fragments;

>10 cm: C_1, violaceous grey (5YR 5/1) altered shales.

Micromorphology

A/(B)-hor., skeleton of small shale fragments, very fine grains and scarce plant remains in good decomposition. The matrix contains clay minerals, various iron oxides and clay-humus complexes. Well-developed microspongy structure with pores and microaggregates of very different sizes; the microaggregates are linked to the firm mass by fine bridges.

C_1-hor., clay-shales rich in very fine opaque grains of iron oxides.

Profile IV

Situation: Cortelazor, altitude 700 m, mountainous relief. Parent material: mica-schists. Vegetation: association climax *Mirteto-Quercetum rotundifolii*.

Soil Horizons

0–10 cm: A, reddish grey (10YR 5/2), loamy sand, crumbly; medium content of organic matter in different degrees of decomposition;

10–20 cm: A/C_1, very pale brown (10YR 7/3), sandy loam, crumbly; rock fragments frequently present;

>20 cm: C_1, very altered mica-schists.

Micromorphology

A-hor., skeleton formed by some altered fine plants remains; few rock fragments and some sand grains. Matrix is formed of clay–humus complexes, flocculated iron hydroxides and dense plasma. The latter encloses the decomposed rocks with red iron oxides which are turning brown. There are also excrements of worms and other little animals which promote the formation of aggregates, cavities and pores.

Profile V

Situation: Cortelazor, altitude 490 m, mountainous relief. Parent material: slates. Vegetation: association climax *Mirteto-Quercetum rotundifolii.*

Soil Horizons
0–15 cm: A/(B), light yellowish-brown (10YR 6/4), sandy loam, crumbly, medium organic matter content; good permeability and root penetration;
15–45 cm: (B_1), brownish-yellow (10YR 6/6), loamy, polyedric crumbs; low permeability
45–70 cm: (B_1)/C, yellow (10YR 7/6), clayey loam, polyedric to laminar; slates at different stages of degradation;
>70 cm: C, chloritic slates.

Micromorphology
A/(B)-hor., skeleton formed of small fragments of very altered chloritic rock with red iron oxides and few plant remains. The clayey or silty matrix contains very homogenously distributed, flocculated, reddish-brown hydroxides, opaque crystallites of iron oxides, and clay–humus complexes, coloured by iron oxides. Irregular microstructure of biogenic aggregates, "worked" through the slate fragments and linked with them in a spongy structure.

(B_1)/C-hor., very altered slates with a dense, slightly birefringent, red plasma, infiltrating and surrounding the rock mass. The plasma contains very fine crystallites of iron (and possibly manganese) oxides.

Profile VI

Situation: Cortelazor, altitude 650 m, mountainous relief. Parent material: chloritic slates. Vegetation: association climax *Mirteto-Quercetum rotundifolii*.

Soil Horizons
0–15 cm: A/(B), dark reddish-brown (5YR 3/3), loamy, crumbly; high organic matter content;
15–50 cm: (B_1), red (2,5YR 5/6), clayey loam, polyedric crumbs; medium permeability and root penetration;
>50 cm: (B_1)/C, very altered slates.

Micromorphology
A/(B)-hor., skeleton formed of small slate fragments, various mineral grains and decomposed plant remains. The silty clay matrix contains brown iron hydroxides and brown clay–humus complexes; when observed in reflected light it shows a red colour due to various iron oxides. Well-developed micro-aggregate structure.

Profile VII

Situation: El Pedroso, altitude 500 m, mountainous relief. Parent material: mica-schists. Vegetation: olive tree plantation (climax vegetation *Quercion-rotundifoliae*).

Soil Horizons

0–20 cm: A_p, reddish-yellow (7,5YR 7/6), sandy, crumbly; low organic matter content;

20–40 cm: (B_1), reddish-yellow (5YR 7/8), sandy loam, compact granular; low permeability and root penetration;

40–65 cm: $(B_1)/C$, reddish-yellow (5YR 6/6), loamy sand, granular; medium permeability.

Micromorphology

A_p-hor., skeleton formed of coarse sand grains and very few plant remains. Soil in thin sections is reddish-brown. It contains flocculated iron hydroxides, very scarce red dense plasma, and probably organo-mineral complexes. There are some small microaggregates between large grains of the skeleton.

(B_1)-hor., skeleton of altered small and large grains, immersed in a red matrix or enclosed by cutans. This is due to the retraction of the fundamental soil mass, which has a more fluid and birefringent contexture than the remaining soil. Dense microstructure with few aggregates, which are principally formed by retraction.

$(B_1)/C$-hor., skeleton of large grains, immersed in a matrix which mainly consists of a dense mass of yellowish-red plasma of fluid contexture; this is caused by infiltration into the altered rock (mica-schist). The matrix also contains minerals from the mica-schists in various stages of alteration. The microstructure is dense with few retraction and conduction voids.

ANALYTICAL DATA

The micromorphological study of the Sierra Morena brown forest soils can be completed and related to the chemical, mechanical and mineralogical analyses of these soils (Kundler, 1959; Brewer, 1960; Paneque, 1961; Lotti; 1962). Tables I, II and III contain the analytical results.

DISCUSSION

Profiles I and II of Mediterranean brown forest soil ("Braunerde") on granite are best known, and their analytical results more easily understood, by thin section study. Microscopic examination of (B)/C-horizons reveals the existence of a dense (probably braunlehm) plasma (Kubiena, 1953; Paneque, 1961), infiltrated in the altered granitic rock. Consequently the structure is compact, the aeration poor, and the texture more sandy in deeper layers. Horizon-A does not show large micromorphological differences. However it seems clear that horizon-(B) of profile I differs from that of profile II because of its higher clay content, compaction, and other facts confirming the genesis and development of profile I under shrubs on ondulate land, and the aluvial origin of profile II.

Profile I shows an almost neutral pH, a medium organic matter content, and a C/N quotient higher than 15. The exchange capacity and the base content increase with depth, reaching a maximum in horizon-(B) which is more humid, less sandy and more clayey (Tables I and II). The sand fraction contains a large proportion of heavy minerals, which consist mainly of hornblende, which increases towards the rock, a sienitic granite. Light minerals (quartz and alkaline feldspars) are also abundant, while medium minerals (plagioclases) are scarce (Table III). Kaolinite is common throughout the

TABLE I

Chemical analysis of Mediterranean brown forest soils of Sierra Morena

Profile	Horizon	Depth (cm)	pH	O.M. (%)	C (%)	N (%)	$\frac{C}{N}$	B.E.C. m.e.q./100	Ca^{2+} Exchangeable	Mg^{2+} Exchangeable
I	A	0–10	6.15	2.33	1.35	0.08	16.8	6.94	163.5	49.6
	(B)	10–30	6.05	0.83	0.48	0.04	12.0	15.90	247.7	108.1
	(B)/C	30–50	6.95	0.29	0.17	0.02	8.5	12.66	204.4	73.0
II	A	0–40	5.30	1.23	0.72	0.05	14.4	4.37	92.2	43.8
	(B)	40–80	5.85	0.55	0.32	0.03	10.6	9.87	120.2	2.1
	C_1	>80	6.07	0.22	0.13	0.02	6.5	–	370.3	140.2
III	A/(B)	0–10	5.35	2.47	1.43	0.10	14.3	6.58	91.4	71.5
IV	A	0–10	5.10	4.03	2.34	0.14	16.7	6.58	103.4	83.2
	A/C_1	>10	5.00	1.83	1.06	0.09	11.7	–	62.5	49.6
V	A/(B)	0–15	5.75	1.81	1.63	0.12	13.6	6.29	76.9	44.8
	(B_1)	15–45	5.60	0.84	0.49	0.07	7.0	13.19	79.4	64.2
	$(B_1)/C$	45–70	6.05	0.19	0.11	0.01	11.0	22.00	101.0	202.9
VI	A/(B)	0–15	6.00	11.72	6.80	0.52	13.0	8.77	132.2	61.3
	(B_1)	15–50	5.25	0.50	0.29	0.02	14.5	–	29.0	44.0
	$(B_1)/C$									
VII	A_p	0–20	5.95	0.43	0.25	0.03	8.3	6.65	120.2	48.2
	(B)	20–40	4.95	0.69	0.40	0.04	10.0	14.30	120.2	92.0
	(B)/C	40–65	4.85	0.40	0.23	0.02	11.5	14.15	96.2	173.7

TABLE II

Mechanical analysis of Mediterranean brown forest soils of Sierra Morena

Profile	Horizon	Depth (cm)	Moisture (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
I	A	0–10	2.32	37.18	35.52	4.90	22.50
	(B)	10–30	5.74	19.36	30.65	5.20	44.80
	(B)/C	30–50	3.11	47.22	28.16	8.10	16.40
II	A	0–40	1.58	34.96	33.40	16.80	13.60
	(B)	40–80	1.45	44.67	29.82	7.20	19.30
	C_1	>80	4.88	54.90	16.70	10.70	16.80
III	A/(B)	0–10	1.51	32.03	10.33	19.20	28.80
IV	A	0–10	1.95	37.85	23.89	8.60	29.90
	A/C_1	>10	2.20	31.55	13.28	12.80	42.10
V	A/(B)	0–15	1.60	37.54	12.30	22.60	27.10
	(B_1)	15–45	4.39	9.39	3.93	76.30	12.20
	$(B_1)/C$	45–70	4.68	16.51	15.87	38.30	29.20
VI	A/(B)	0–15	5.54	16.60	22.00	47.40	13.80
	(B_1)	15–50	1.70	9.20	29.30	32.60	28.40
	$(B_1)/C$						
VII	A_p	0–20	1.29	44.85	31.18	8.70	17.60
	(B)	20–40	2.75	26.63	11.05	48.04	13.20
	(B)/C	40–65	2.79	33.19	16.06	18.10	33.20

whole profile, illite is highest in horizon-A, and montmorillonite is included in (B) and (B)/C (Table III).

In profile II the pH and organic matter content are lower. The C/N quotient and base exchange capacity are smaller, and exchangeable Ca and Mg are lower in horizon-A and (B) (Table I). Coarse sand increases towards the rock, while the percentage of fine sand and silt is highest in the upper horizons (Table II), possibly because of fluvial deposition. In the sand fraction heavy minerals increase towards the rock, a sienitic granite with much hornblende. Horizons-A and (B) contain accessory minerals (staurolite and titanite) foreign to the granitic rock; light minerals are abundant and increase in the upper horizons. Illite and kaolinite are the most abundant clay minerals; in horizon-A there is some montmorillonite and in hor.-(B) chlorite (Table III).

The Sierra Morena Mediterranean brown forest soil, on shale and slate, is generally a shallow soil, permanently young because of erosion except in privileged sites. Profiles III and IV belong to this type of soil. Micromorphological study of them adds much information to the field description, and also explains the results of chemical and mineralogical analyses satisfactorily.

Microscopic observation of the rock from profile III in thin section shows that the slate is rich in fine grains of iron oxides (hematite and magnetite) which, together with clay minerals, determine the brown reddish grey colour of the original material. The well humified organic matter in horizon A forms organo-mineral complexes and leads to the formation of

TABLE III

Mineralogical analysis of Mediterranean brown forest soils of Sierra Morena

Profile	Horizon	Depth (cm)	Sand minerals (0.4–0.04 mm) Light minerals D = 2.68	Medium minerals D = 2.68–2.9	Heavy minerals D = 2.9	Relative frequency of main heavy minerals[1]	
I	A	0–10	48.25	2.75	49.00	+++ Hrn	++ He
	(B)	10–30	49.34	6.10	44.56	++++ Hrn	+ He
	(B)/C	30–50	42.40	12.70	44.90	+++++ Hrn	
II	A	0–40	97.37	-	2.63	++ Hrn	+ St
	(B)	40–80	86.90	4.30	8.80	+++ Hrn	+ St
	C_1	>80	78.25	7.05	14.70	+++++ Hrn	
III	A/(B)	0–10	30.39	69.50	0.11	++ Hrn	+++ He
IV	A	0–10	29.35	28.05	42.40	+++++ Cl	
V	A/(B)	0–15	43.10	48.60	8.30	++++ Cl	+ Ep
	(B_1)	15–45	78.49	19.40	2.11	+ Cl	+++ Ep
	$(B_1)/C$	45–70	94.15	4.30	1.55		++++ Ep
VI	A/(B)	0–15	42.30	41.00	16.70	++++ Cl	
	(B_1)	15–50	72.60	24.30	3.10	+++ Cl	+ Ep
	$(B_1)/C$	>50	85.06	14.40	0.54	+ Cl	++++ Ep
VII	A	0–20	75.36	11.45	2.92	++++ Cl	+ Ep
	(B)	20–40	90.99	8.78	0.23	+++ Cl	+ Ep
	(B)/C	40–65	90.91	8.90	0.19	+ Cl	++ Ep

[1] +++++ Predominant = 75–100%
++++ Dominant = 50– 75%
+++ Abundant = 25– 50%
++ Common = 10– 25%
+ Present = 0– 10%

[2] For the identification the following methods have been used: DTA, X ray, (%)K_2O E.G. retention and B.E.C.

a well-developed spongy micro-structure. However a reddish colour, from the rock iron oxides, can be observed in thin section.

The soil has a low pH, medium organic matter content, a C/N quotient near 15, a low base exchange capacity and base content (Table I), and a loamy texture (Table II). The sand fraction contains few light and heavy minerals, and a large amount of medium ones. Heavy minerals consist mainly of hematite, hornblende, chlorite, zircon, and magnetite; clay minerals are fundamentally illite and chlorite (Table III).

Profile IV is a ranker or young Mediterranean brown forest soil on mica-schist. It is from a higher (700 m) and more hilly land than that of profile III. Microscopic observation of the soil in thin section shows a rather complex organization, as described above. As in profile III the pH is low, the organic matter content high, the C/N quotient near 17, the base exchange

Relative frequency of main heavy minerals[1]			Clay minerals[2] Relative frequency[1]				Profile
			+++ Ill	+++ K			I
			+ Ill	+++ K		++ Mont	
				+++ K		+++ Mont	
+++ Ti			+++ Ill	+++ K		+ Mont	II
++ Ti			+++ Ill	+++ K	+ Cl		
++ Cl	+ Zr	+ Mg	+++ Ill		+++ Cl		III
			+++ Ill	++ K	+ Cl		IV
+++ He	++ Li		+++ Ill	+ K	+++ Cl		V
+++ He	++ Li		+ Ill	+++ K	+ Cl		
+++ He	++ Li		+ Ill	++++ K			
+++ He	++ Li		+++ Ill	+ K	+++ Cl		VI
+++ He	++ Li		+ Ill	++++ K			
+++ He	++ Li		+ Ill	++++ K			
+ He	+ Zr	+++ Mg	+++ Ill	+++ K			VII
+ He		++ Mg	++ Ill	++++ K			
	+ Zr		++ Ill	++++ K			

Hrn = Hornblende
He = Hematite
St = Staurolite
Ti = Titanite
Cl = Chlorite

Zr = Zircon
Mg = Magnetite
Li = Limonite
Ep = Epidote

Ill = Illite
K = Kaolinite
Mont = Montmorillonite
Cl = Chlorite

capacity low, the base content low in horizon-A (Table I), and the texture is silty-sandy (Table II).

The more permanent sand minerals are heavy ones, almost all being chlorites. Light and medium minerals occur in equal quantities (Table III). Clay minerals are illite, kaolinite and chlorite (Table III).

Another variety of Mediterranean brown forest soil in the Sierra Morena shows the characteristics of being developed on "red loam (Rotlehm) sediment", principally shale. Profiles V, VI and VII represent those soils which normally are located in areas higher than 500 m, with a humid microclimate. Under these conditions the "browning" of the red soil can be important. The intensity of this process allows the establishment of the following genetical series; red loam sediment (paleosoil)→"Ranker" or browned red loam→ Mediterranean brown forest soil on shale.

In these profiles there is a contrast between the upper reddish-brown horizon-A, and the underlying eroded red or reddish yellow paleosoil. In thin section the distinction is very clear; especially obvious are the differences between the skeletons, their iron oxide and hydroxide contents (Kubiena, 1956, 1962), and their contents of brown clay–humus complexes. The microstructure of brown and red horizons also differs greatly; micro-aggregate formation is well-developed in the A-horizon, while in the red paleosoil birefringent plasma and compact structure occur.

The analytical data corresponding to these soils are very interesting. Red horizons are the most acid and have the lowest organic matter content, and the C/N quotient in general is near to ten. The base exchange capacity increases with depth (Table I), together with the clay content of these generally loamy soils, and coarse sand increases towards the soil surface (Table II).

The mineralogical composition of the sand and clay is very similar in the three profiles (Table III). An increase in the proportion of heavy minerals can be observed in the A-horizon due to the abundance of chlorite, which shows a certain "antipathy", in the profile, for epidote. Iron minerals (hematite, magnetite and limonite) are relatively abundant. There is a decrease in the content of medium minerals (plagioclases) in the red horizons, and an increase in light minerals (quartz and alkaline feldspars).

Clay minerals are fundamentally illite, kaolinite and chlorite; illite + chlorite increase in brown horizons, while kaolinite increases in red ones (Table III).

SUMMARY AND CONCLUSIONS

The micromorphological and petrographical study carried out on the three main varieties of Mediterranean brown forest soil of the Sierra Morena (Spain) can be summarized in the following conclusions:

(1) The Mediterranean brown forest soil (meridional "Braunerde") on granite (sienitic) shows an abundant skeleton, mainly formed by alkaline feldspars, quartz and hornblende. They exist in various proportions, according to the degree of substitution of micas by amphibol in the rock.

The matrix contains flocculated iron hydroxides in horizons-A and (B), organo-mineral complexes and clay. The clay minerals are illite (more abundant in horizon-A), kaolinite (uniformly distributed through the profile), montmorillonite (associated with a compact structure and almost neutral reaction of the medium), and a little chlorite, possibly contained in the rock or proceeding from the transformation of micas.

The micro-structure of horizon-A shows micro-aggregates, and is very different from that of horizons-(B)/C and C. The latter shows birefringent dense plasma, infiltrated through the altered rock or from the structure of horizon-(B), which is more or less porphiritic.

(2) The Mediterranean brown forest soil on shale and slate has a mineral skeleton largely formed by very small fragments of altered rock. These microfragments play an important role in the soil structure, together with the organo-mineral complexes of the matrix. The matrix also contains finely flocculated iron hydroxides of actual formation, and fine-grained

crystallized iron oxides either contained in the sedimentary rock (shale) or proceeding from a red paleosoil ("Rotlehm"), which can be traced in thin section. Clay minerals, illite and chlorite, are mainly a heritage from the rock; the kaolinite proceeds from the red soil. The microstructure is formed by irregular, well-developed aggregates linked to the skeleton.

(3) Finally, the Mediterranean brown forest soil on red soil on shales shows a complex profile. The skeleton of A-horizon is similar to that of actual Mediterranean brown forest soil on shale, but has a larger content of rock altered by an old pedological process. The matrix contains flocculated iron hydroxides, reddish-brown organo-mineral complexes, and crystallized iron oxides proceeding from the old red soil and the rock. Clay minerals, illite and chlorite, are of secondary formation, as well as inherited from the original material.

The micromorphology of the red sediment shows characteristics typical of a relict red loam ("Rotlehm"), more or less red in colour. The mineral skeleton is formed by fine grains and shale fragments; red plasma of fluid structure with rather fine birefringent crystallites; peptized iron hydroxides and iron oxides (goethite and hematite).

The sand fraction is mainly formed by light minerals (alkaline feldspars, quartz, etc.), a few medium minerals (plagioclases, etc.), and scarce heavy minerals (epidote, hematite, limonite, etc.). The clay fraction contains mainly kaolinite and a little illite.

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