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THE AGES AND SOILS OF TWO LEVELS OF "RAÑA" SURFACES IN CENTRAL SPAIN

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ABSTRACT

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The geomorphology of two rañas and a specimen soil profile on each have been studied in the Province of Guadalajara, Central Spain. The rañas were first delineated on an aerial photograph, then examined in the field for further identification and for the preparation of topographic profiles. Two soil profiles were described and sampled by horizons. Analyses were made of the samples for particle size distribution, pH, cation exchange relations and organic matter plus some observations on mineralogy of clay and fine sand fractions. Results of the study support earlier suggestions that the younger raña surface (S-1) is of Donau age (Middle Villafranchian) but indicate that the second (S-2) should be assigned to the Middle—Upper Pliocene (Lower Villafranchian). The soil profiles were found to be an Alfisol on the younger and an Ultisol on the older raña which is consistent with a greater age for the latter.

INTRODUCTION

In western Spain, the term "raña" is used by the public to designate any flat geomorphic surface with a detrital covering and with entrenched valleys at its margins. Geologists, on the other hand, give to this term both morphologic and stratigraphic meanings; it can mean either the landform or the detrital covering.

Rañas are associated with quartzitic mountain ranges of the so-called "Macizo Hespérico" (Central and West Spain) and usually constitute a glacis-piedmont type of surface. Generally the sediments of the rañas overlie a previous erosion surface (Menshing, 1958; Mabesoone, 1961; Molina, 1975; Espejo, 1978). In Spain, no raña formations have been described associated with calcareous or granitic mountain ranges.

Rañas originated before the entrenchement of actual rivers (Mabesoone, 1961; Vaudour, 1977; Espejo, 1978) and, consequently, appear at higher altitudes than the sequences of river terraces and normally constitute the divides between the basins of two rivers.

Gomez de Llarena (1916) began scientific studies on raña formations. Since then, ages ranging from Miocene (Oehme, 1935) to Quaternary (Muñoz and Asensio, 1974) have been attributed to these formations. At present an Upper Pliocene—Villafranchian is the most generally accepted age (Mabesoone, 1961; Aparicio, 1971; San José, 1971; Molina, 1975; Martin, 1977; Vaudour, 1977; Espejo, 1978), although more detailed studies are needed to support this statement and to find out whether there were one or several periods of raña formation as suggested by Vaudour (1977) and Espejo (1978).

The purpose of this investigation was to characterize the geomorphology, geology and soils of a pair of raña formations at different elevations in the same area with the hope of improving current estimates of their ages.

STUDY AREA

The study area lies in the Province of Guadalajara in Central Spain, as shown in Fig. 1. Several raña surfaces are present in the neighborhood of La Puebla de Beleña as parts of the divide between the basins of the River Jarama and River Henares. The general appearance of the locality is shown on the aerial photograph in Fig. 2.

The rañas selected for this study are outlined on maps in Figs. 1 and 2. They constitute two geomorphic levels: a higher one called by us the "S-2" raña formation and a lower one, the "S-1" raña formation.

Climate

Climatic data are from El Vado (41°00'N 3°10'W; elevation 1000 m). The mean annual temperature is 12°C and the average rainfall 797 mm per year. Average annual evapotranspiration (Thornthwaite) is 713 mm. There is a pronounced summer drought and a surplus of water in winter.

Vegetation

The upper raña (S-2) has a maquis cover in which representative shrubs are *Cistus ladaniferus*, *Rosmarinus officinalis* and *Halimium umbellatum*. Isolated junipers (*Juniperus oxicedrus*) are also present. This raña was cultivated between 1940 and 1950.

The lower raña (S-1) is cultivated to winter cereals except for the strong slopes around its margins. These have a maquis cover, like that of the upper raña (S-2), with occasional junipers and a few oaks (*Quercus faginea*), the latter mainly near the southern end.

FIELD AND LABORATORY METHODS

Geomorphic surfaces were first delineated on an aerial photograph having a scale of 1 : 30.000 (1956 USAF-B flight) and were further identified by

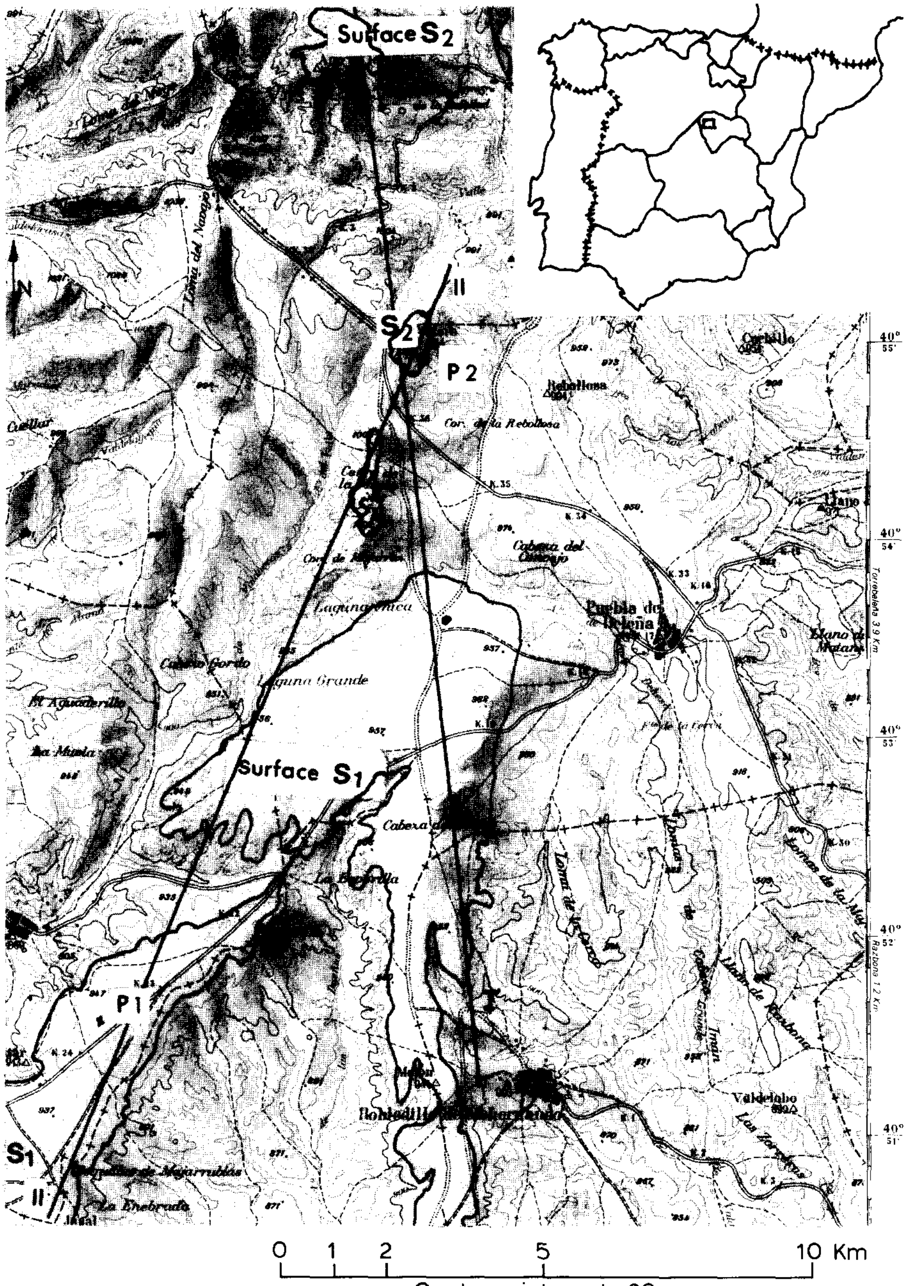

Fig. 1. Map showing location of study area in Spain, outlines of the two raña surfaces, and sites of the two soil profiles.

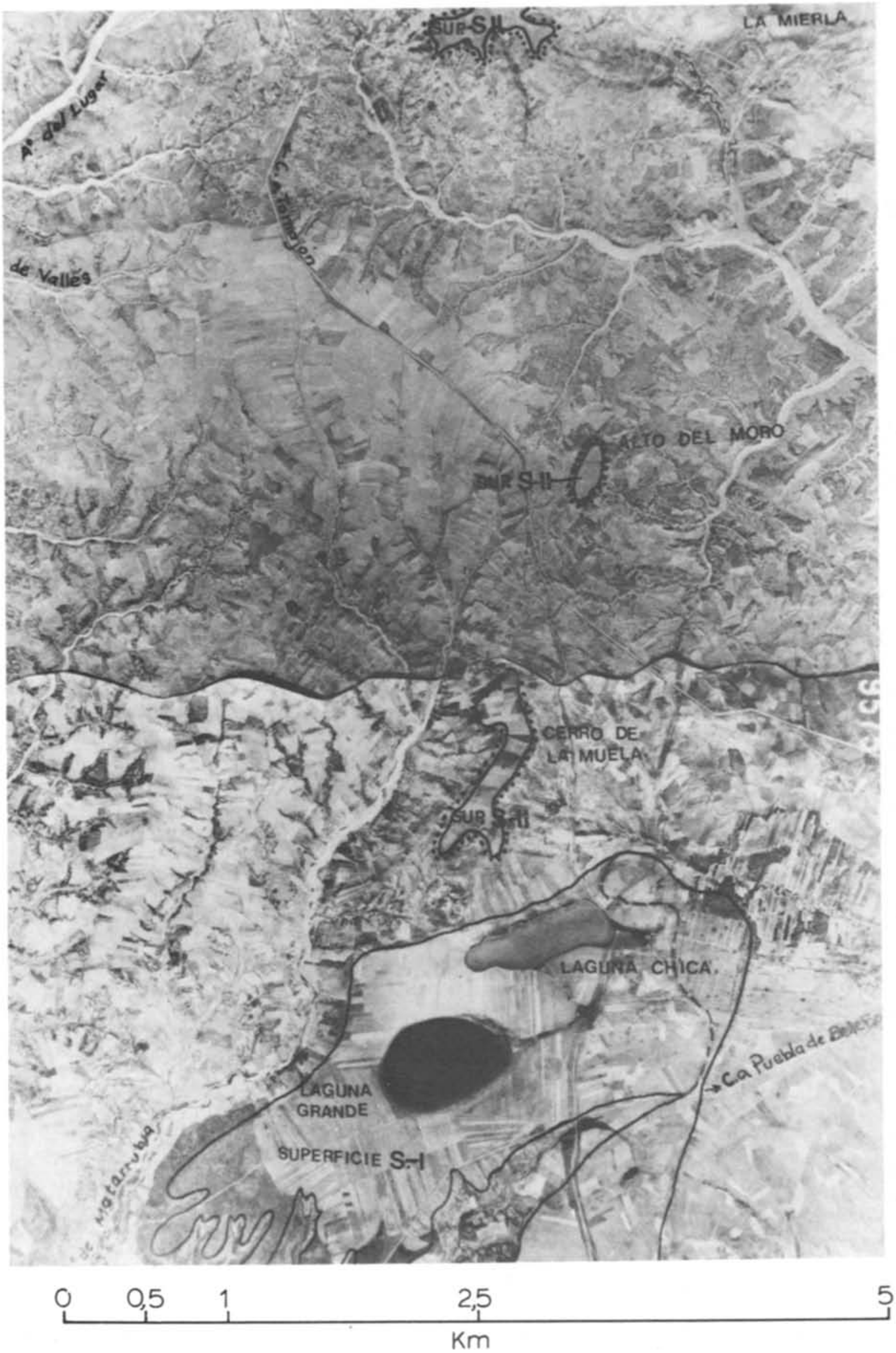

Fig. 2. Aerial view of the study area in the Province of Guadalajara (Central Spain). The large area of the lower raña (S-1) and the several small areas of the upper raña (S-2) are delineated on the photograph.

field traverses. Topographic profiles were prepared from aerial photographs and from the 1 : 50,000 Topographic Map number 485 (Spanish Topographic National Service). This map has contour intervals of 20 m.

The sites at which the two soil profiles were described and sampled are shown on the map in Fig. 1. Site of profile P-1 is shown in the lower left portion of the map; that profile represents soils of raña S-1. Site of profile P-2 is shown near the central upper part of the map where a small area of the higher raña S-2 had been delineated. Standards, terminology for describing soil horizons and horizon designations are from F.A.O. (1977) guidelines. Colour for moist specimens are from Munsell Soil Color Charts (1954). The soil profiles were classified according to Soil Taxonomy (1975).

Soil samples were taken to the laboratory where they were air-dried and passed through a 2-mm mesh sieve prior to analyses. Those analyses followed published methods. Particle size distribution was determined by the method of Kilmer and Alexander (1949). Fine clay was separated and determined by centrifugation according to Jackson (1969). The pH was measured with a glass electrode in both soil—water (1 : 2.5) and soil—KCl (1 *N* KCl; 1 : 2.5) suspensions. Organic matter was determined by the method of Walkley and Black (1934). Cation exchange capacity (CEC) was measured by an NH_4OAc procedure (U.S. Dept. Agric., 1972). In the extracts, Na and K were determined by flame emission, Ca and Mg by atomic absorption. Extractable Al was removed with 1 *N* KCl solution and determined according to Yuan (1959). "Free" iron oxides were estimated by dithionite—citrate—bicarbonate extraction (Mehra and Jackson, 1960); iron in the extracts was measured by atomic absorption. Total iron was also determined by atomic absorption after destruction of silicates by HF (Pratt, 1965). Fine sand in one sample from each profile was split into light and heavy fractions by bromoform (sp. g. 2.82); mineralogy of each fraction was determined with a petrographic microscope according to Perez Mateos (1965). Clay minerals were identified by X-ray diffraction according to Whittig (1965).

RESULTS

Geomorphology

The lower of the two raña formations (S-1) is a large platform extending for several kilometres in a NE—SW direction and having a general slope gradient of about 0.5% to the southwest. The highest elevation of the platform is about 950 m. Its surface is marked by several shallow depressions ranging in diameter from a few hundred metres to nearly 1 km (Figs. 1 and 2). These depressions are usually filled with water in winter and are dry in summer. The northeast and higher end of this raña formation (S-1) is near the Cerro de la Muela, a hill capped by the sediments of the higher raña S-2. The southwest end of the platform breaks off into a series of narrow, finger-shaped ridges set apart by creek valleys. On all sides the platform is flanked

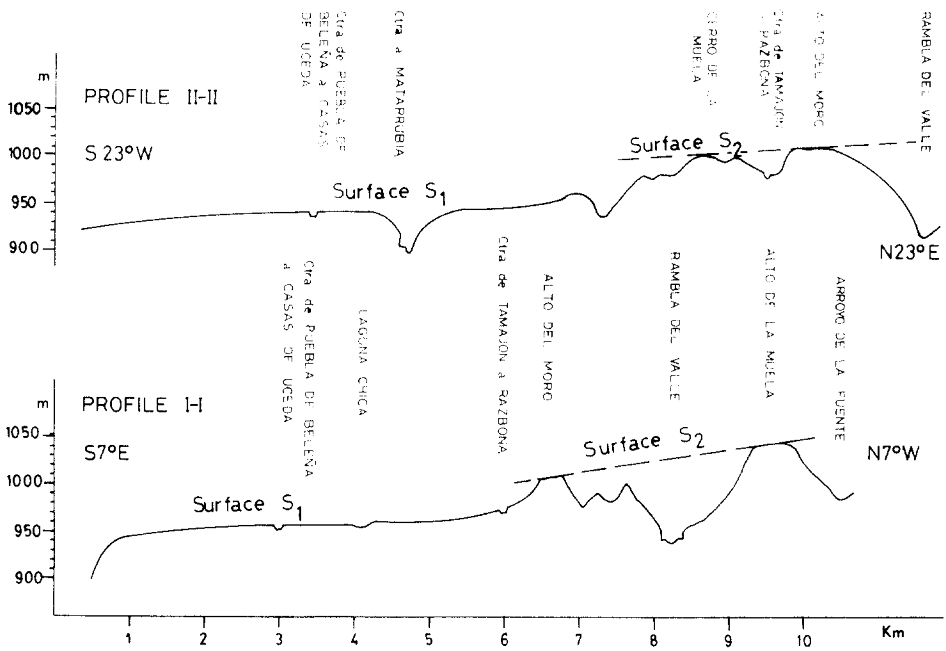

Fig. 3. Topographic profiles of two transects with directions S23° W—N 23° E and S7° W—N7° E, to show relationships in elevation between the two raña surfaces.

by gullies entrenched into the detrital covering of the raña and underlying rock. This raña was described previously by Vaudour (1977) and Medina (1977).

The higher raña formation (S-2) consists of several small platforms scattered over a distance of several kilometres. These are believed to be remnants of a once-larger platform, but each is now no more than a few hectares in size. Each is flanked on all sides by gullies, similar to those around raña S-1. Elevations of the remnants decrease from north to south (Alto de la Muela, 1040 m; Cerro del Moro, 1010 m; Cerro de la Muela, 1000 m). Individual remnants are level or nearly so. A line drawn from one to others over their entire extent, however, indicates that prior to dissection the platform had a general slope gradient of about 0.8% to the south.

Fig. 3 shows two topographic profiles following the N23° E and N7° W directions. Both show some topographic characteristics of the S-1 and S-2 raña formations. These profiles show clearly that no topographic continuity seems to exist between the surfaces of the two raña formations.

Geology and lithology

In both raña formations the basement rock consists of a psammo-pellitic arkose with intercalations of psammites and with common pebbles of quartz and quartzite of Miocene age (I.G.M.E., 1963).

The detrital covering (i.e., the raña materials) in both formations can be described as an oligomictic conglomerate consisting essentially of quartzite pebbles and blocks in a psammo-pellitic matrix. These sediments seem to be quite uniform in thickness, mostly about 2—3.5 m as observed in the walls of gullies.

The source area for the raña sediments giving rise to the conglomerates is the same for the two rañas and lies to the north. That area is rich in metamorphic rocks such as gneisses, schists and quartzites but also has sedimentary marls and limestones. Only part of those source rocks are now represented in the detrital covering. Quartz and quartzite are abundant in the skeleton and matrix of both rañas. Other rocks are lacking except for an occasional strongly weathered slate pebble.

The matrix of the deepest portions of the detrital covering of the lower raña (S-1) contains finely divided carbonates, specially near the southern end of the platform. Those are considered to be of pedogenic origin rather than from the source rocks to the north.

The S-1 raña formation was dated by Vaudour (1977) as belonging to Donau (Middle Villafranchian). In higher raña formation S-2, raña sediments overlie the M-2 erosion surface of Schwezner (1936). This surface was defined and dated by Schwezner as belonging to Middle Pliocene and is widely represented in Central Spain.

Soil profiles

Profile P-1. The profile was examined and sampled in a wheat stubble field in June, 1980.

Physiographic location: platform of S-1 raña formation.

Topography: nearly level, less than 0.5% slope gradient.

A_{u1}	0 to 25 cm	Yellowish brown (10YR 5/4) fine sandy loam; very weak subangular structure; hard (dry); many fine and medium roots; common fine tubular pores; 20% by volume of quartzite pebbles less than 5 cm in diameter; gradual smooth boundary to
A_{u2}	25 to 35—40 cm	Yellowish brown (10YR 5/5) fine sandy loam; weak subangular structure; hard (dry); many fine and medium roots; common fine and very fine tubular pores; 40% by volume of quartzite pebbles less than 10 cm in diameter; clear wavy boundary to
B_{t1}	35—40 to 110 cm	Strong brown to yellowish brown (7.5YR 5/6—10YR 5/6) clay; blocky structure influenced by stones; hard (dry); common medium roots, dead toward lower boundary; common very fine and fine tubular pores; 60% by volume of quartzite pebbles less than 10 cm in diameter; gradual boundary to
B_{t2}	110 to 170 cm	80% strong brown to yellowish brown (7.5YR 5/5—

10YR 5/6) and 20% light gray (2.5Y 7/1), the last around stones, principally toward lower boundary; clay; blocky structure influenced by stones; hard (dry); isolated dead medium roots; 70% by volume of quartzite pebbles and blocks, some of them up to 40 cm in diameter; isolated black concretions of less than 5 mm in diameter; gradual boundary to

B_{t3} 170 to 230 cm — 60% strong brown to yellowish brown (7.5YR 5/5—10YR 5/6), 20% light gray (2.5Y 7/1) and 20% dark red (2.5 YR 3/5); these colours appear distributed in nearly horizontal bands which are continuous through matrix and quartzitic stones; sandy clay; blocky structure influenced by stones; firm (moist) without roots; 70% by volume of quartzite pebbles and blocks, some of them up to 40 cm in diameter; most of these blocks and pebbles are soft enough to be breakable by hand and show an inside colour segregation similar to that exhibited by the matrix; some isolated slates also strongly weathered; gradual boundary to

B_{t4} 230 to 260 cm — 35% light gray (2.5Y 7/1), 35% dark red (2.5YR 3/5) 20% dusky red (10R 3/5) and 10% strong brown to yellowish brown (7.5YR 5/6—10YR 5/6); these colours appear distributed in nearly horizontal bands which are continuous through matrix and quartzitic pebbles; clay; nearly laminar structure determined by colour segregation; zones of 2.5Y and 7.5YR colour, slightly sticky and plastic (wet), and zones of 10R and 2.5YR colour very firm (wet), 70% by volume of quartzite pebbles and blocks, some of them up to 40 cm, with hardness similar to those of above horizon.

Profile P-2. The profile was examined and sampled in an abandoned winter cereal field in November, 1980.

Physiographic location: table-like hilltop of S-2 raña formation

Topography: nearly level, less than 0.5% of slope gradient

A_{u1} 0 to 15—20 cm — Brown (7.5YR 5/4) fine sandy loam; weak subangular structure; firm (moist); very abundant very fine, fine and medium roots; common fine and medium tubular pores; 10—20% by volume of quartzite pebbles less than 7 cm in diameter, some of them with a black patina similar to "desert varnish"; gradual boundary to

A_{u2} 15—20 to 50 cm — Brown (7.5YR 5/5) fine sandy loam; firm (moist);

		many fine and medium roots; common fine and medium tubular pores; 10—25% by volume of quartzite pebbles less than 12 cm in diameter; abrupt boundary to
B_{t1}	50 to 85 cm	Strong brown (7.5YR 5/6) with dark red zones (2.5 YR 4/6) toward lower boundary; clay, blocky structure influenced by stones; firm (moist); many medium roots; very common very fine and fine tubular pores; 60% by volume of quartzite pebbles less than 15 cm in diameter; isolated quartz pebbles; gradual boundary to
B_{t2}	85 to 150 cm	55% very pale brown (10YR 7/2), 25% red (10R 4/6) and 20% strong brown (7.5YR 5/6); these colours appear distributed in nearly horizontal bands which are continuous through matrix and quartzite pebbles; clay; nearly laminar structure determined by colour segregation; zones of 10YR and 7.5YR colour are firm (moist) and zones of 10R colour very firm (moist); few medium roots, most of them dead; 70% by volume of quartzite pebbles and blocks, less than 10 cm in diameter although there are some isolated ones up to 25 cm; most of these blocks and pebbles are soft enough to be breakable by hand and show an inside colour segregation similar to that exhibited by the matrix; gradual boundary to
B_{t3}	150 to 200 cm	60% very pale brown (10YR 7/2), 30% red (10R 4/6) and 10% strong brown (7.5YR 5/6); these colours are distributed in nearly horizontal bands which are continuous through matrix and quartzite pebbles; clay; nearly laminar structure determined by colour segregation; zones of 10YR and 7.5YR colour are firm (moist) and zones of 10R colour very firm (moist); isolated dead medium and coarse roots; 70% by volume of quartzite pebbles and blocks of similar size and hardness to those of above horizon; abrupt boundary to
$2B_{t4}$	200 cm	Red (10R 4/6) very fine arkosic sediment with frequent channels of 1—5 cm in diameter filled with a light gray (10YR 7/1) material. The contact area between this white material and red matrix of about 0.5 cm thickness, has a brownish yellow colour (10YR 6/6); moderate blocky subangular structure; very hard (dry); without stones; clay coats are very common in light gray material of channels; without stones.

Clay coats were observed in the B horizons of both profiles in the field. Those were best expressed within cracks in rock fragments in the lower parts of the profiles.

Analytical data

These are given in four tables for the horizons of the two profiles. Particle size distribution is given in Table I. The data for pH, cation exchange capacity (CEC), exchangeable bases, base saturation, extractable Al and organic matter are in Table II. Extractable and total iron, both expressed as oxides, are given in Table III, whereas minerals in the clay fractions are listed in Table IV.

Both profiles have appreciably less fine sand in their deepest horizons than in those near or at surface (Table I). Profile P-1 has much more coarse sand in the deepest layers, whereas the distribution is nearly uniform in profile P-2. Proportions of clay and the ratio of fine clay to total clay increase markedly from the A to the B horizons in both profiles. These data bear on the original vertical uniformity of the regoliths and on consequent identifications of the deeper horizons.

Data in Table II show more differences between the profiles than those in Table I. Base saturation values in B horizons are lower in the P-2 profile and decrease with depth. Extractable Al is appreciably higher, which is consistent with the base saturation and pH values. Cation exchange capacities expressed as meq./100 g of clay in B horizons are lower in the P-2 profile and accord with its clay mineralogy.

Clay mineralogy, shown in Table IV, was much the same for all horizons of the two profiles. The primary small differences were the absence of hematite in all but the deepest horizons of profile P-2, more goethite in those horizons than in any others, and some minerals of the smectite group in the lower A and upper B horizons of profile P-1.

Slight differences were also found in the mineralogies of the fine sand fractions from the upper B horizons of the two profiles. The light fractions were 86% quartz, 9% K-feldspars and 5% muscovite in profile P-1 as compared to 91% quartz, 4% K-feldspars and 5% muscovite in profile P-2. The proportion of feldspars was lower and the grains had a cloudy appearance in profile P-2, suggesting greater weathering. Dominant minerals in heavy fractions were rutile, tourmaline and zircon plus staurolite in the sample from profile P-1.

DISCUSSION

Classification of the profiles in Soil Taxonomy

The diagnostic features of both profiles are their argillic horizons (B_t horizons). The A horizons are not dark enough nor high enough in organic

TABLE I

Particle size distribution in the horizons of the two profiles of raña soils

Horizon	Depth (cm)	Particle size distribution (%)					Fine clay / Total clay
		coarse sand (2—0.2 mm)	fine sand (0.2—0.02 mm)	silt (0.02—0.002 mm)	clay 0.002 mm	fine clay 0.0002 mm	
Profile P-1							
A_{u1}	0 to 25	10.0	61.0	20.5	10.0	1.6	0.16
A_{u2}	25 to 35—40	11.0	58.0	15.0	12.5	2.1	0.17
B_{t1}	35—40 to 110	6.0	28.0	8.0	56.0	19.0	0.34
B_{t2}	110 to 170	8.0	38.0	8.5	44.0	16.0	0.40
B_{t2}	170 to 230	27.0	26.0	5.0	43.5	18.2	0.42
B_{t3}	230 to 260	24.0	28.0	4.0	47.0	19.6	0.41
Profile P-2							
A_{u1}	0 to 15—20	18.0	67.0	12.0	5.0	—	—
A_{u2}	15—20 to 50	23.0	62.0	12.0	5.5	1.2	0.21
B_{t1}	50 to 85	10.0	30.0	8.0	50.5	20.2	0.40
B_{t2}	85 to 150	13.0	29.5	9.0	47.5	21.0	0.44
B_{t3}	150 to 200	11.0	36.0	4.0	49.0	22.5	0.46
$2B_{t4}$	200	10.0	32.0	13.0	44.0	15.4	0.35

TABLE II

Chemical characteristics of the horizons of the two raña soils

Horizon	Depth (cm)	pH (1 : 2.5)		C.E.C.*[1]		Exch. bases (meq./100 g soil)				V*[2] (%)	Extractable Al (meq./100 g soil)	Organic matter (%)
		H_2O	KCl	meq./100 g soil	meq./100 g clay	Ca	Mg	K	Na			
Profile P-1												
A_{u_1}	0 to 25	6.4	5.0	6.0	—	4.8	0.7	0.2	0.1	97	0.0	1.1
A_{u_2}	25 to 35—40	6.3	4.8	6.2	—	5.2	0.8	0.2	0.1	100	0.0	0.6
B_{t_1}	35- 40 to 110	6.0	4.5	20.5	36.0	11.0	4.0	0.4	0.3	79	0.0	
B_{t_2}	110 to 170	5.2	3.5	16.5	37.5	6.0	1.2	0.4	0.2	48	2.1	tr
B_{t_3}	170 to 230	5.3	3.6	13.2	29.0	5.2	0.8	0.3	0.3	50	1.3	tr
B_{t_4}	230 to 260	5.5	4.0	11.2	23.0	5.6	1.0	0.2	0.4	64	0.0	tr
Profile P-2												
A_{u_1}	0 to 15—20	5.8	4.7	3.0	—	2.5	0.4	0.2	0.1	100	0.0	0.9
A_{u_2}	15—20 to 50	5.6	4.5	3.1	—	2.7	0.3	0.4	0.1	100	0.0	0.4
B_{t_1}	50 to 85	5.2	4.0	16.0	28.5	7.0	1.8	0.5	0.2	60	tr	tr
B_{t_2}	85 to 150	4.6	3.6	11.0	25.0	2.2	0.8	0.2	0.1	30	5.5	tr
B_{t_3}	150 to 200	4.5	3.4	9.0	20.0	1.2	0.5	0.1	0.1	22	7.0	tr
$2B_{t_4}$	200	4.5	3.6	9.0	20.5	0.7	0.8	0.1	0.2	21	5.4	tr

*[1]Cation exchange capacity.
*[2]Base saturation.

TABLE III

"Free" Fe-oxides and total Fe in the horizons of the two raña soils

Horizon*[1]	Depth (cm)		"Free" Fe_2O_3 (%)	Total Fe_2O_3 (%)	"Free" Fe_2O_3 / Total Fe_2O_3
Profile P-1					
A_{u1}	0 to 25		1.45	2.07	0.70
A_{u2}	25 to 35—40		1.50	2.00	0.75
B_{t1}	35—40 to 110		3.20	4.00	0.80
B_{t2}	110 to 170		4.15	4.88	0.85
B_{t3}	170 to 230		4.35	5.11	0.85
B_{t4}	230 to 260	(1)	8.20	9.30	0.88
		(2)	0.90	1.05	0.85
Profile P-2					
A_{u1}	0 to 15—20		0.90	1.12	0.80
A_{u2}	15—20 to 50		0.95	1.15	0.82
B_{t1}	50 to 85		4.05	4.75	0.85
B_{t2}	85 to 150		4.45	4.95	0.90
B_{t3}	150 to 200	(3)	9.35	10.35	0.90
		(4)	1.05	1.20	0.87
$2B_{t4}$	200	(5)	7.10	8.05	0.88
		(6)	0.50	0.55	0.90

*[1]Numbers in brackets following the depth values refer to plinthic areas (see profile descriptions):
(1): 7.5YR 5/5 plus 2.5YR 3/5
(2): 2.5Y 7/1
(3): 10R 4/6 plus 7.5YR 5/6
(4): 10YR 7/2
(5): 10R 4/6
(6): 10YR 7/1

matter to qualify as mollic or umbric epipedons and must be considered ochric epipedons. Those are not criteria for placement of the profiles in soil orders of the American system (Soil Survey Staff, 1975). Particle size distribution indicates that one or more lithological discontinuities are present in each profile. Despite the probable discontinuities, however, the amounts of clay in the B horizons seem high enough so that those would qualify as argillic horizons in any case. Moreover, contrasts in proportions of clay between A and B horizons are large and the ratios of fine clay to total clay are higher in B than in A horizons. The presence of clay coats in deeper horizons is further evidence for identification of argillic horizons.

Profile P-1 (raña S-1). This is placed in the Alfisol order on the basis of morphology and base saturation. The lowest base saturation in the argillic horizons is slightly below 50%. Under the prevailing climatic conditions, I expect the moisture regime to be xeric and the profile is therefore assigned

TABLE IV

Clay minerals in the horizons of two profiles of raña soils from X-ray diffraction data

Horizon	Depth (cm)	Kaolinite	Illite—mica	Smectite groupe	Goethite	Hematite
Profile P-1						
A_{u1}	0 to 25	××	×	n.p.	n.p.	n.p.
A_{u2}	25 to 35—40	×××	×	×	n.p.	n.p.
B_{t1}	35—40 to 110	×××	××	×	×	n.p.
B_{t2}	110 to 170	×××	×	×	×	n.p.
B_{t2}	170 to 230	×××	×	n.p.	×	n.p.
B_{t3}	230 to 260	×××	×	n.p.	×	n.p.
Profile P-2						
A_{u1}	0 to 15—20	×××	×	n.p.	n.p.	n.p.
A_{u2}	15—20 to 50	×××	×	n.p.	n.p.	n.p.
B_{t1}	50 to 85	×××	×	n.p.	×	n.p.
B_{t2}	85 to 150	×××	tr.	n.p.	×	tr.
B_{t3}	150 to 200	×××	tr.	n.p.	××	×
$2B_{t4}$	200	×××	tr.	n.p.	××	tr.

×, ××, ××× mean, respectively: small, moderate and high contents; n.p.: not present; tr: traces.

to the suborder of Xeralfs. Because of the clay distribution in the profile, it is placed in the great group of Palexeralfs.

Profile P-2 (raña S-2). This is placed in the Ultisol order on the basis of morphology and base saturation. Base saturation is below 35% near the middle of the argillic horizon and continues to decrease with depth. Under the same climatic conditions as profile P-1, the second profile is also believed to have a xeric moisture regime and is therefore assigned to the suborder of Xerults. The distribution of clay in the profile and the limited information on sand mineralogy suggest that the profile would best fit the great group of Palexerults.

Post-depositional weathering of raña materials

Marked changes are believed to have occurred in the sediments after they were laid down. This inference rests on two lines of evidence.

(1) A wide variety of rocks is present in the source area from which the raña sediments came, with slates, shales, gneisses, micacites, quartzites, marls and limestones as the most common. The original raña sediments are therefore presumed to have had moderate to high proportions of weatherable minerals such as biotites and plagioclases. Those minerals, however, are virtually absent from the fine sand fractions of the upper B horizons of the two profiles. Those sand fractions consist of highly resistant minerals such as quartz, zircon and tourmaline with small amounts of K-feldspars, as pointed

out in the previous section. Amounts of the K-feldspars are small but twice as large (9%) in profile P-1 as in profile P-2 (4%). This difference suggests greater weathering of materials in the latter profile. A further indication of post-depositional weathering is the dominance of kaolinite in the clay fractions of all horizons of the soils; the small differences between the clay mineralogy of the two profiles, are consistent with greater weathering in profile P-2.

(2) In both profiles, quartz and quartzite form the "skeleton", the rock and mineral fragments larger than coarse sand. Other rocks and minerals are not represented among the coarse fragments except some isolated slates in the S-1 raña formation (see description of profile P-1). Moreover, the quartzite below a depth of several decimetres (160 cm for profile P-1 and 80 for profile P-2), are soft and as indicated in the profile descriptions can be crushed by hand. Parallel evidence of the weathering of quartzite fragments has been obtained by Icole (1970, 1973) in the piedmont surfaces of the northeastern Pyrenees of Donau and Upper Pliocene age, principally in the latter, Espejo (1978) also found a similar degree of weathering affecting quartzites of raña formations of the Sierra de Altamira y las Villuercas (southwestern Spain). In contrast, such strongly weathered quartzite fragments are unknown in the sediments of river terraces, all of post-Donau age.

Age of raña formations

According to Vaudour (1977), the S-1 raña formation is probably of Donau age (Middle Villafranchian). I think that the S-2 raña formation is probably older. This hypothesis is based on:

(a) *Sediment alteration.* Icole (1970, 1973) suggested in two comparative studies of pebble alterations in sequences of river terraces and piedmont surfaces in the northeastern Pyrenees that the process responsible for the transformation of quartzites into ferruginous sandstone might have taken place under a warm—moist climate. According to Icole these climatic conditions occurred mainly in the Middle—Upper Pliocene (Lower Villafranchian) and less markedly at the Middle Villafranchian. As shown above, the transformation of quartzites into ferruginous sandstone is more marked in the S-2 raña formation than in the S-1. Moreover, the mineralogy of clay and fine sand fractions suggests that the mineralogical alteration has been more pronounced for the S-2 formation.

(b) *Profile morphology.* The differences in the morphology and composition of the soils of the two raña surfaces are small, but they are consistent with the idea of a greater age for the S-2 raña formation. The differences in base saturation and extractable Al indicate slightly greater leaching for profile P-2.

Alfisols and not Ultisols are the soils developed on all the levels of river terrace sequences close to our area (Torrent, 1976; Medina, 1977). Accordingly, profile P-1 (S-1 raña formation), classified as an Alfisol, and having ultic characteristics (base saturation in B_t horizons is about 50%) appears to lie genetically mid-way between the profiles developed on the highest (oldest) river terrace levels and the P-2 profile which is an Ultisol.

(c) *Geomorphic evidence.* As raña formations occupy higher topographic positions than river terraces and usually are the divides between two river basins, I have assumed that they formed before river entrenchment through the Quaternary. In addition, the S-2 raña formation might be considered older than the S-1 because of its higher topographic position. According to Schwezner (1936) the sediments of S-2 raña formation overlie an erosive surface of Middle Pliocene age which suggests that this raña formation is younger than Middle Pliocene.

One interpretation of the geomorphic evolution of the two raña surfaces would involve both climatic change and tectonic movement. The S-2 raña could have originated after the Middle Pliocene. Later, leached soils (Ultisols) were formed under a humid—warm climate. During the Donau, tectonic movement occurred to the lower part of the S-2 surface, which then became the S-1 raña. This was accompanied by a change to a drier climate. The present S-1 surface should also have received new sediments from the original source area to replace bases in the Ultisol profiles so that they became Alfisols. Similarities in morphology of deeper horizons of the two profiles studied are consistent with this idea.

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