GEAMORPHOLOGICAL ASPECTS OF THE PISUERGA DRAINAGE AREA IN THE CANTABRIAN MOUNTAINS (Spain)

BY

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CHAPTER I

INTRODUCTION

General

Along the northern coast of Spain a mountain belt extends which is known as the Cantabro-Asturian Mountain Chain. This chain runs parallel to the shoreline while the summit region (which attains heights of over 2000 m) lies within a distance of some 40—50 km from the coast. The western half of the chain is built up by Palaeozoic rocks and is called the Asturian Chain; the eastern half is built up by Mesozoic rocks and is known as the Cantabrian Chain (Llopis Llado in Solé Sabaris, 1952). From W to E gradually younger rocks are encountered: in the western and central parts of the Asturian Chain the mountains are formed by the oldest Palaeozoic rocks (Cambrian, Ordovician, Silurian) whereas farther to the East Devonian and Carboniferous rocks are the relief forming ones. This Palaeozoic core dips under a cover of Mesozoic sediments, and from there eastward the mountains bear the name Cantabrian Chain.

The area investigated by us *) lies at the transition zone where the Asturian chain meets the Cantabrian chain, that is to say where the Palaeozoic mountain core dips under the Mesozoic cover.

From the southern slopes of the mountain chain a great many rivers, tributaries of the Duero, flow into the Meseta of Old Castile, accompanied by extended terrace sediments. This Meseta of Old Castile lies directly south of the mountain chain, only separated from it by a belt of folded Mesozoic rocks which is extremely narrow in the western part and which widens considerably southeast of Cervera de Pisuerga.

In the present paper we shall deal with the geomorphology of the southern part of the mountain chain, and in particular with the fluviatile terraces mentioned above, which spread out, broadly speaking, in the region where the rivers leave the chain. Some of the terraces, however, extend over considerable distance inward into the mountains. The area chosen for this study is indicated in fig. 1 and includes, from W to E, the upstream parts of the drainage areas of the Rio Pisuerga, the Rio Rubagón and the Rio Camesa. Thus the region is bordered in the W by the drainage system of the R. Carrión, in the N by the main divide between the Duero system and the northern rivers which drain directly into the Gulf of Biscay. From Peña Tres Mares (2175) this divide splits up into two branches which enclose the Ebro system; the boundary of our region then follows the southern watershed between the Ebro and the Duero systems. In the S the area is bordered by a minor divide running approximately from W to E, south of the Rio Pisuerga.

In some descriptive parts of the text it could not be avoided to use a number of local names. As far as possible they are noted on the maps which

*) Field work was carried out during the summers of 1956, '57 and '58.

join this thesis and which the reader is invited to compare. Full topographical details are given by the Mapa de España 1:50.000, sheets 81 Potes; 82 Tudanca; 106 Camporredondo de Alba; 107 Barruelo de Santullán; 108 Las Rozas; 132 Castrejón de la Peña; 133 Prádanos de Ojeda; and 134 Polientes (fig. 1).

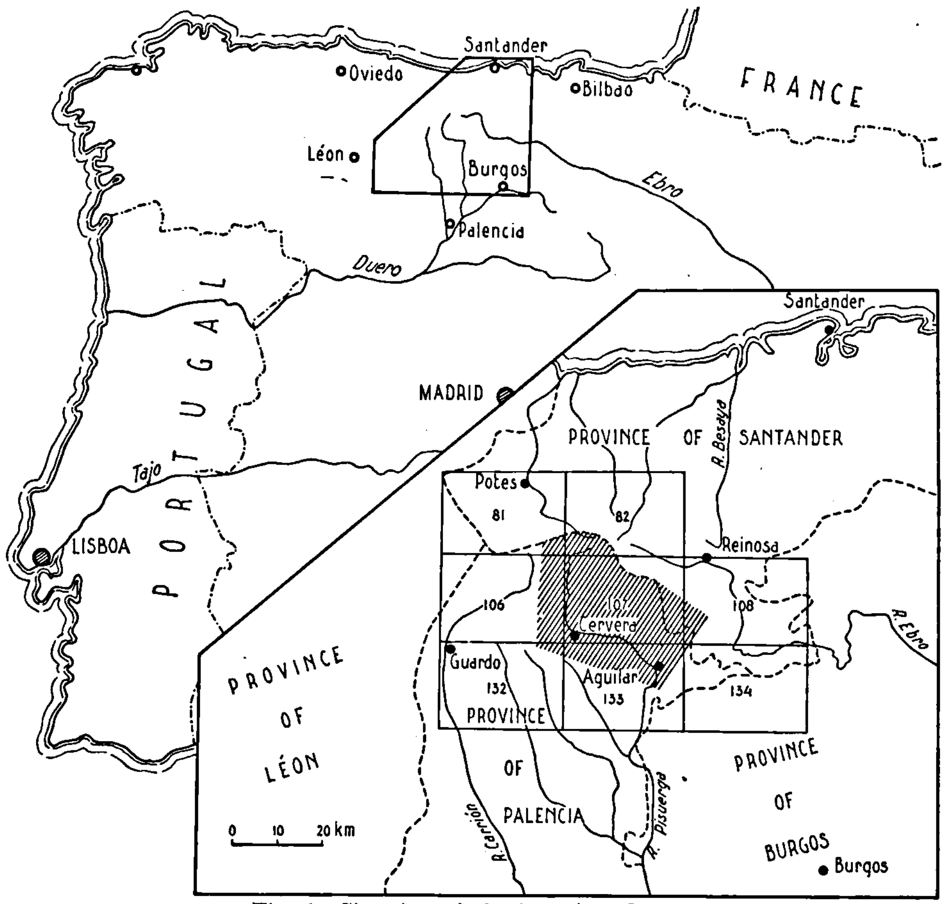


Fig. 1. Situation of the investigated area.

The investigated area in wider morphological connection

To the S a marked boundary separates the Cantabrian Mountains from the Meseta of Old Castile, a high plain with mesas built up of horizontal or subhorizontal Tertiary layers, mainly clays, marls, conglomerates and evaporites. The Meseta belongs to the Duero basin and rises very slowly northward from about 800 m near the present Duero valley to about 975 m at the boundary with the Cantabrian Mts. Between the Tertiary sediments and the Palaeozoic core of the Cantabro-Asturian Mountain Chain, a narrow zone of folded Mesozoic formations is intercalated as was remarked above, which widens from Cervera de Pisuerga to the SE. This folded zone has a relief different from that of the Meseta, but it has not the real mountain relief of the Cantabrian Mountains. This zone was called "Pays Plissé" by Ciry (1939), and this name will be used in the present paper and on map 1.

The Palaeozoic core of the mountain chain dips eastward under a cover of Mesozoic formations; some tongues of Triassic extend westward, e. g. in the Peña Labra (2018), the Valdecebollas (2139), and at Ligüerzana (cf map 2). The investigated area in fact belongs wholly to the drainage area of the Rio Pisuerga, the Camesa being a tributary of the Pisuerga, and the Rubagón in its turn being an affluent of the Camesa. The Pisuerga itself, finally, is a tributary of the Duero; the latter rises in the Iberic Mountains at about 2100 m and flows in westerly direction to the Atlantic Ocean into which it discharges at Oporto. We shall now consider briefly the drainage areas of the three rivers which will be studied in this thesis.

The Rio Pisuerga rises at a height of about 2000 m on the northern slope of the Valdecebollas; another important branch originates near the Puerto de Piedras Luengas on the southern slope of the Peña Labra at about 1900 m altitude. The first mentioned branch takes in the main a westerly direction, the latter a southward course, and both branches join north of San Salvador de Cantamuda. From here they continue southward as far as Cervera de Pisuerga, where the river leaves the Palaeozoic mountains. From here it takes an eastern and southeastern course along the southern border of the Palaeozoic mountains, passing through a folded Mesozoic zone (Ciry 1939; cf map 2). After the confluence with the Rio Camesa, some kilometres south of Aguilar de Campóo, the river again bends southward. After the boundary between Mesozoic and Tertiary deposits is passed north of the village Alar del Rey, it continues in a mainly southern direction till it discharges into the Duero at Tordesillas (Vallodolid). The length of the Rio Pisuerga is 283 km; it drains an area of 14526 sq.km. We shall deal with its course as far as the confluence with the Camesa.

The Rio Rubagón rises at the southeastern slope of the Valdecebollas, at about 1950 m altitude. In its upper part it passes the Triassic deposits in an east-southeasterly direction, then from Brañosera downward it passes through Carboniferous rocks, in a south-southeasterly direction; off Cillamayor where the river leaves the core of the mountains, a narrow belt of Triassic is again passed. From here it flows through folded Mesozoic rocks, and at Quintanilla de las Torres it lets out into the Rio Camesa which, as we saw, is a tributary of the Rio Pisuerga.

The Rio Camesa originates on the southern slope of the Peña Rubia (Sierra de Hijar) at a height of 1880 m. As far as Reinosilla it streams through Triassic rocks in southeastern and east-southeastern directions. Then at Mataporquera it bends to the South and flows through Keuper, Jurassic and Cretaceous sediments to its outlet into the R. Pisuerga, south of Aguilar de Campóo. The Camesa area is bordered to the E and N by the drainage area of the Ebro system, so that at these sides the watershed is at the same time the main divide between the Ebro and Duero systems, that is between the Atlantic Ocean and the Mediterranean.

Morphological contrasts between northern and southern flanks of the Cantabrian Mountains

The summits of the Cantabrian Mountains attain heights of over 2500 m more to the W in the central part; in the area treated in this paper they are slightly lower but heights of over 2000 m are frequently reached (Valdecebollas 2139, P. Tres Mares 2175, P. Labra 2018, etc.). The passes in the northern divide mostly lie at heights of over 1300 m. This divide runs at a distance of 30—50 km from the Gulf of Biscay, measured as the crow flies; along the bottom of the valleys, e. g. of the Rio Deva, the distance is about 67 km. Over this distance the water falls, from the Piedras Luengas pass, 1329 metres, which is an extremely steep course for so short a river. The result of this steep fall is a topography with gorges, deep valleys, and very steep slopes; the mean fall of the rivers is in the order of 22 ‰. This type of topography is present all along the northern coast of Spain, as the moutain chain and the divide run parallel to the coast line over a distance of hundreds of kilometres.

To the South the Cantabro-Asturian Mountains are bordered by the Meseta of Old Castile which in the Duero basin has a mean level of about 900 m. The Meseta can be considered as a temporary base level for the rivers draining the southern slope of the Mountains. *)

The result is that the valley floors on the southern flank of the Cantabrian Mountains are at a much higher level than the valleys of the northern flank.

Over about equal distance the rivers running south fall about 1000 m less than those on the northern slope; besides, the precipitation on the northern half is much greater than in the southern part, so that the erosive power of the northern rivers is much greater than that of the southern system. This results in the formation of strikingly different topographies on the northern and on the southern sides of the Cantabrian Mountains. The northern part shows steeply cut valleys as described above. The southern part shows a topography of wide open valleys having flat valley floors even in the upstream parts. Locally the valley floors attain the dimensions of valley plains. From the valleys long denudation slopes rise up with variable slope angles, which are considerably less steep than the valley slopes of the northern region. The difference is illustrated in fig. 2.

It is clear that this great difference in erosive capacity results in a rapid southward shifting of the main divide because the northern rivers cut down more rapidly than the southern ones, and thus capture upstream parts of them. Illustrative is e. g. the capture-to-be of the whole upstream region of the Ebro by the R. Besaya, as was described by F. Hernandez Pacheco (1944). East of Reinosa the Ebro lies at 850 m height; the pass to the Besaya valley, at a small distance, is only at 865 m.

North of the Piedras Luengas pass, on the right bank of the valley of the Rio Bullón (a tributary of the Rio Deva), several traces are found of ancient upstream parts of headwaters of the Pisuerga system. They were captured because of the rapid headward erosion of the Rio Bullón.

As the R. Ebro is not a recurrent river, it falls more rapidly than the Rio Duero so that there is also a contrast in relief between the Ebro and Duero systems. This contrast, though not so impressive as the other, is everywhere clearly notable, for instance east of Quintanilla de las Torres. Here

*) The Meseta rivers can be considered as recurrent rivers. The real downstream part is attained only in Portugal; the greater part of e. g. the Duero flows on the Meseta in a pseudo downstream course; near Zamora it sinks rapidly to its true downstream course after having passed a part with a very steep gradient at the boundary between the high Meseta and the Portuguese coastal plain. In the fall zone a new middle or even upstream region is formed.

Fig. 2. Contrasts in relief.
Above: south of the divide, Rio Areños valley, looking north.
Below: north of the divide, Rio Deva in La Hermida gorge.

the divide makes a great curve in westerly direction to that it is situated less than 1 km from the Camesa. The pass is very low and rises only some 15 m above the Camesa level which is at 900 m. The valley on the other side of the divide has a regular and considerable fall down to 740 m at the confluence with the Ebro. Geologically speaking in the "near future" a capture of the upper Camesa by the Ebro system is to be expected. It is clear that similar captures will have taken place earlier, too. If only we consider the very irregular course of the divide at Quintanilla, we may imagine that the valley of the Arroyo Mardancho once made part of the Duero system. When considering the large number of right-angled bows in the course of the Ebro, we may suppose that many captures and changes in drainage have taken place as a result of the rapid backward erosion of the Ebro. It is beyond the scope of the present paper, however, to pay further attention to this subject, though it would be very attractive to do so.

Climate and climatic contrasts

Climatologically, too, the Cantabrian Mountains form an important boundary. The northern part is ruled by an Atlantic climate; the high mountain zone has of course a mountain climate; to the South the climate rapidly becomes a semi-arid continental one.

The continental climate which rules the Old Castilian Meseta shows a great annual temperature-oscillation; the mean temperatures of the warmest and the coldest months differ 16—20°C; the mean annual temperatures are between 10° and 12°C. The number of days with precipitation is 75—110. On the Biscay Coast, 150—175 days per annum have precipitation, and here the temperatures of the warmest and coldest month are only 10—12° apart. The mean annual temperature is 13.5—14.5°C. In the mountains a mean annual temperature of about 10°C is found (altitude not stated) (Masachs in Solé Sabaris, 1954).

The Biscay Gulf Coast has an abundant precipitation ranging between 1000 and 2000 mm per annum; the highest mountain zones receive over 2000 mm. On the southern side of the mountains the annual precipitation decreases rapidly, the Old Castilian and Leonese Meseta having an annual precipitation of only 300—500 mm.

In table 1 the climates of the Biscay Coast and the Meseta are compared; the data are derived from Solé Sabaris (1954).

TABLE 1.

Comparison of climates of Biscay Coast and northern Meseta; data derived from Masachs, in Solé Sabaris, 1954.

	Biscay Coast	Northern Meseta
Mean annual temperature, °C.	13.5—14.5	11.5
Mean maximal temperature, °C.	38.9	36.5
Mean minimal temperature, °C.	— 4.1	— 11
Annual temperature oscillation, °C.	12	18.5
Mean temperature January, °C.	8.5	2.7
Mean temperature August, °C.	20	20
Number of days with precipitation	165	85
Precipitation in July, mm	60	15
Days with snow, per annum	4	15
Degree of covering of sky, in tenths	6	5
Mean annual precipitation, in mm	1155	410

F. Hernandez Pacheco (1944) gives data on the climate of the region between Cervera de Pisuerga and Reinosa which is exactly the area considered by us. The data are for the period 1921—'30.

The mean annual temperature for Cervera (at about 1000 m) is 9.6°C, for Barruelo de Santullán (1040 m) 10—11°C, for Reinosa (848 m) 9.4°C.

The mean temperatures in August and in January at Cervera are 18.1°C and 2.2°C respectively and at Reinosa 16.9°C and 3°C.

The extreme temperatures in this period were in Cervera —15°C and 37°C, in Reinosa —14°C and 36°C.

Mean annual precipitation: In Cervera was recorded 987.1 mm, in Reinosa 950.7 mm and in Barruelo about 960 mm. The mean numbers of days with precipitation in Cervera and Reinosa were 70.1 and 126.7 per annum, respectively. Snow fell on 21.0 and 32.5 days per annum. The precipitation concentrates in the first four and the last four months of the year, so that in summer it decreases very considerably. Winters are hard and long, January, February and March having heavy snowfall.

Covered sky occurs in Reinosa about 100 days a year, in Cervera about 80. In the summit region of the mountains the sky is covered about 250 days. Hernandez Pacheco calculates that the 0°C year isotherm must lie at about 1900 m. At heights over 1500 m, precipitation exceeds 1000 mm a year. In the summit level snow can fall all the year long, but in June, July and August this seldom occurs.

The most frequent wind directions in the summit level are NW, W and SW; in Reinosa NE, NW and SW, and in Cervera SW. These differences are caused by the local topographies.

Fig. 3 illustrates the climatic fluctuations in Cervera and Reinosa.

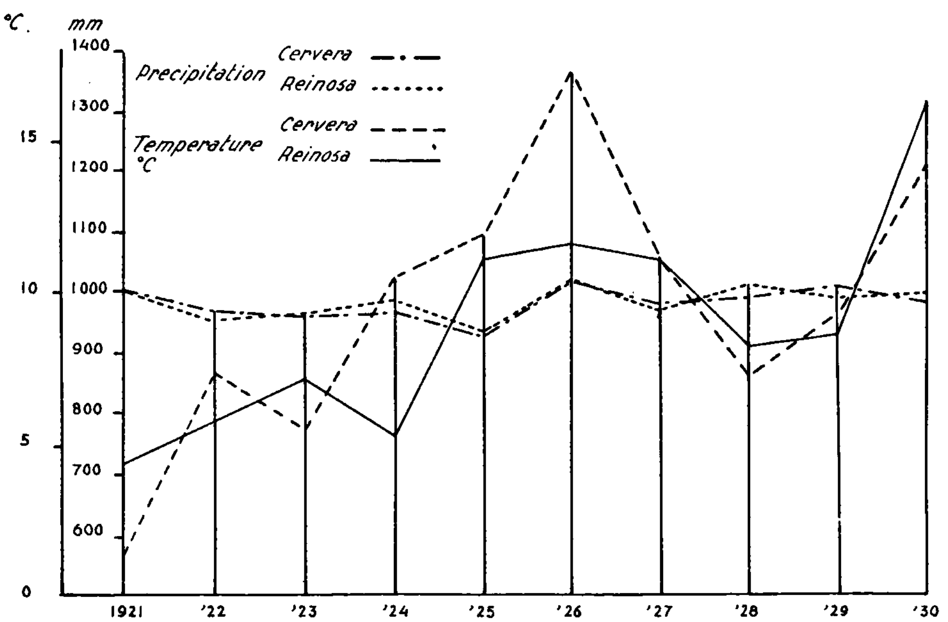


Fig. 3. Mean annual precipitation and temperature in Cervera and Reinosa. Period 1921—1930. After F. Hernandez Pacheco.

Previous authors

Very little special geomorphological research has been carried out in this region, though geological studies are quite numerous. In this paragraph we shall only consider publications which are important for our geomorphological study of this region.

One of the most important publications is by F. Hernandez Pacheco (1944): "Fisiografía, Geología y Glaciarismo Cuaternario de las Montañas de Reinosa". In the first part the physiography of the Campo de Suso valley is discussed, which is outside of our region. It is the upstream system of the R. Hijar, which is the most important tributary of the upper Ebro system. Then the geological and tectonical features of this region are treated and after this, the geomorphology of the valley. Finally, a number of climatological data for the Cervera-Reinosa region are given.

In the second part glacial phenomena and relief forms are discussed extensively. To us the chapters on the "Western Chain" and the Valdecebollas region are the most important. Therefore, the study of glacial landscape types, in the present paper, plays only a subordinate role, and for more complete data may be referred to the just mentioned publication.

H. Quiring published in 1939 a study on "Die Ostasturischen Steinkohlbecken", in which he describes some terraces of the Rio Pisuerga. Three levels were distinguished, which were compared with the Hauptterrasse, Mittel- and Niederterrasse of the Rhine.

A study in which a part of the region discussed by us is considered, was published in 1939 by R. Ciry: "Etude Géologique d'une partie des provinces de Burgos, Palencia, Leon et Santander". The first part of the book deals with the stratigraphy and palaeontology of the Mesozoic and Tertiary deposits of the described region; the second part is a discussion of the geological structures and the third part is a summary of the results. In the maps which accompany his publication, "Alluvions Anciennes" and "Alluvions Modernes" are distinguished. They have been mapped accurately but no further examination was carried out on them.

J. Kanis (1955) studied the geology of the eastern fringe of the Sierra del Brezo, and mentioned some fluviatile terrace regions along the R. Pisuerga. He distinguished two levels, one at a relative height of 160 m, and a Lower Terrace, and uttered serious objections against Quiring's interpretation. He doubted the possibility of accurate dating of the terraces, unless archaeological of palynological data should be obtained. Moreover, a "Piedmont alluvial plain", south of the Sierra del Brezo, is discussed.

H. Karrenberg (1934) carried out a research on the post Hercynian development of the Cantabrian Mountains. The stratigraphy is discussed from the Permian upward and in the second part the tectonical features are studied. In the first part the occurrence of two Tertiary "Rumpfflächen" in the Cantabrian Mountains is mentioned, one from post Oligocene times and another dating from the Pliocene.

A. de Alvarado and A. H. Sampelayo (1945) in their study on the western part of the Rubagón basin also mentioned the Pisuerga terraces.

In a paper mainly dealing with the Tertiary deposits A. J. Pannekoek (1957) mentions the terrace sediments of the R. Pisuerga.

Publications, in which our region is referred to, but in which the morphology is more or less subordinate, or in which the whole region only plays a subordinate part, are quite numerous. We mention only the most important of them.

Carlé (1947); Obermaier (1921): both studies relate to glacial phenomena in the whole of Spain. Nussbaum & Gygax (1951—52): glacial morphology of the Cantabro-Asturian Mountains; Llopis Llado (1954) on the tectonics of the Asturian Mountains; Wagner (1955) on the stratigraphy and tectonics of the Barruelo region; De Sitter (1955) on the geology of the Pisuergabasin, and the same author (1957) on the structural history of the southeastern part of the Cantabro-Asturian Mountain Chain.

In a number of geological and geographical works on the whole of Spain, descriptions and data on our region, in wider connection, can be found. They are mentioned in the list of references.

Methods

Mapping of the various morphological units took place with the Mapa de España 1:50.000 as a base (fig. 1). Detailed maps were made on the same base. Much of the preparatory work and the field work was carried out with the aid of aerial photographs, which were available for the greater part of the region. Only the eastern and southern parts have been investigated without the help of aerial photographs.

Pebble composition analyses of the terrace sediments were carried out in the field on pebbles with a maximal diameter > 2 cm. The maximal diameters were measured and after that they were grouped into the size classes 2—4, 4—8, 8—16, 16—32 and > 32 cm diameter. The type and colour of the pebbles were determined on fresh rupture surfaces. The pebbles were gathered from as small a surface as possible, mostly of 1—3 squ. metres. A great many components were distinguished in the countings but many of them have been united into groups in the diagrams, for the sake of clearness.

Much has been written on the number of pebbles required for reliable results, and the numbers recommended by the various authors range from 300 to 1000. It should be noted that these quantities are required for gravel with, in general, dimensions of 0.5 to 2 cm diameter (Zeuner, 1933; Van Straaten, 1946; Kremer 1954).

The pebbles in our area, however, have much larger dimensions (up to 32 and even over 50 cm) whereas the finer pebble fractions are subject to many local complications, as we shall see later on in this paper. After some test-countings we had the experience that, for the coarse pebble and cobble fractions considered by us, determination of 100 pebbles is sufficient for a reliable result, if not more than a few groups have to be distinguished. The errors, then, may be within a range of some 5 % to both sides.

Roundness of pebbles was measured in the field by means of a "cible morphoscopique" (A. Cailleux). For various reasons, to be discussed in a following chapter, the roundness was measured only on pebbles with a maximal diameter of more than 4 cm. The roundness index is expressed by the Cailleux' formula

$$I_e = \frac{2r^e}{L} \cdot 1000$$

in which I_e is the roundness index

L is the maximum length of the pebble
r^e is the smallest radius of curvature, measured in the main plane of the pebble, which is defined as the plane through L and l, in which l is the maximum dimension in a plane perpendicular to L.

The measurements were carried out on quartzitic pebbles. Only at very few localities where quartzite pebbles were not sufficiently available, some other types with almost equal properties as to hardness and resistance were also taken into consideration, e. g. quartzitic sandstones and hard homogeneous conglomerate pebbles. At some places where the sediments hardly contain any quartzite (cf Chapter X) roundness measurements were carried out on the hardest pebbles available. In general, special precautions were taken that the results remained more or less comparable to those of quartzite measurements.

As a rule 100 pebbles were measured; in some cases only 50 measurements could be carried out. The data are represented by frequency curves; to the left of the Y axis the percentages of recently broken pebbles are plotted; that are those pebbles that have broken after the sedimentation by recent or subrecent weathering at an outcrop surface; their roundness, of course, is zero.

Grain size of particles < 2000 μ. The samples were examined in the laboratory of the Geological and Mineralogical Institute, Leiden, Holland. Preparatory work on the samples was the usual one: drying, treatment with H_2O_2, HCl and HNO_3. Then the clay fraction up to 32 μ was determined by the pipet method, and the sand and silt fractions from 16-2000 μ by sieving. The results are presented in histograms and log-cumulative graphs.

Rondness of quartz grains was determined on the size fraction 500-150 μ. The measurements were carried out by means of a binocular microscope with an enlarging of × 20, with a microscope-"cible" mounted in the lefthand ocular. The diameters were calculated afterwards from the cible measurements and the roundness index was again obtained by the formula:

$$I_e = \frac{2\,r_s}{L_s} . 1000$$

in which L_s is the maximum length, r_s the smallest curvature radius in the plane perpendicular to the direction of view, and I_e the roundness index.

I_e was measured on 100 grains. The results are plotted in frequency diagrams.

Our method of preparatory work was somewhat modified from Cailleux's, who only washed with water. Because of the thick coatings of ferruginous material on the grains it was necessary to boil with diluted or even concentrated HCl and HNO_3. All analyses were made in the Geological and Mineralogical Institute, Leiden.

Heavy minerals were determined in the usual way, after preparatory treatment with H_2O_2, HCl and HNO_3. The samples were sieved through a 500 μ sieve and separated by bromoform (spec. grav. 2,89). After mounting in slides by canada balsam, 100 minerals of each slide were determined under the microscope. The results are grouped in tables and graphs, while a short description of some properties of the minerals is also given.

CHAPTER II

MAIN GEOLOGIC FEATURES

The different relief types present in our region are, at least partly, connected with the geologic properties of the area. Therefore we shall summarize here the main geologic features from data after publications by Karrenberg (1934), Ciry (1939), Quiring (1939), De Sitter (1955 and 1957), Wagner (1955) and Kanis (1956). For full details on the geology the reader is referred to the authors cited.

Intrusive rocks

Though intrusive rocks are present in various localities, they have little significance for the geomorphologist. According to De Sitter (1955), they are of a porphyric structure, and cause only little thermal metamorphism in their aureoles. Karrenberg (1934) considers them as ophites from Keuper times. In a following chapter we shall see that their influence on the heavy mineral associations is only small and of local importance.

Devonian

Devonian occurs in a zone in the northwestern part of the region (cf. map 2), west and northwest of San Salvador de Cantamuda, with a narrow belt running southward. The eastern border is formed by a large fault line, which seems to play a very important role in the structural history of this region. An isolated occurence of Devonian is found in the mountains of San Julián.

The Devonian consists, in this region, of rather hard and resistant quartzitic sandstones and quartzites, alternating with limestone banks.

Carboniferous

The whole of the upper Pisuerga basin upstream of Cervera, except for the Devonian rocks, consists of Carboniferous deposits, in which three lithological units can be distinguished: limestones, shale-sandstone complexes, and conglomerates.

Namurian-Viséan occurs both in a reef facies, consisting of massive limestones, and a Culm facies, probably extending into the Westphalian A, with shales, sandstones and conglomerates. The reef limestones ("Caliza de Montaña") form the Sierra del Brezo west of Cervera de Pisuerga, a high mountain chain which finds an abrupt eastern termination at Cervera. In the eastern part of the Pisuerga basin, the Namurian-Viséan occurs as shales, sandstones and conglomerates, with limestone reefs as cliffs and isolated peaks. This zone extends, with some interruptions, as far as the Rubagón basin near Barruelo de Santullán. West of Cervera the Culm facies is found in a belt north of the Sierra del Brezo; here it is partly covered by terrace gravel.

Westphalian B. — Between the Namurian (and Westphalian A?) and the Westphalian B an important angular unconformity has been found, the result of one of the Hercynian orogenetic phases, the Sudetic phase, which is here named Curavacas phase (De Sitter).

The Westphalian B is known only as a conglomerate, the Curavacas conglomerate, with an enormous thickness of up to 1000 m. It is named after the 2520 m high peak of the Mt. Curavacas, and continues in a belt in a northwestern direction. This belt lies between the terrace-covered Culm zone and the Devonian. The conglomerate has a matrix with mostly a considerable clay content; its sand fraction is absolutely without sorting and equally distributed over all fractions. In this matrix, pebbles of generally large to very large dimensions are embedded. These cobbles and boulders consist of very resistant quartzites or quartzitic subgraywackes (Kanis, 1956). For briefness' sake they will be called quartzites throughout this paper. These pebbles, which are well rounded, are again important for the later geological history because terraces are found to be covered with pebbles originating from this conglomerate.

Westphalian C & D. — In the Pisuerga basin the Westphalian C & D occurs in the whole eastern and northeastern part. Two lithologic units are important: a shale-sandstone complex, and limestones. The shale-sandstone complexes build up the Westphalian C and the Lower and Middle Westphalian D, and contain a number of coal seams. All transitions between shale and sandstone are present; in general there is a rapid alternation of layers, and the sandstone beds are thin. Therefore as regards resistance to erosion and to weathering the whole group may be considered as a unit. The limestones rise up from the shale-sandstone complex as individual mountains. In the Sierra Corisa, a row of hills south of the Rio Castillería, and elsewhere, they occur in larger ridges. The limestone is resistant to erosion and very conspicuous in the topography.

Stephanian A occurs in the centre of the basin in a zone between the Devonian, from which it is separated by the above mentioned fault line, and the Westphalian C & D. This series, named Barruelo series, again consists of shales, sandy shales and sandstones with a number of coal seams and limestones. Apart from the Pisuerga region,it is found in the Rubagón basin, around Barruelo de Santullán, where it contains conspicuous coarse conglomerates.

Stephanian B-C is found north of the Devonian of the San Julián hills, and consists of conglomerates, shales and sandstones. The conglomerate is named after the Peña Cilda, a hill top in this region.

Between Stephanian A and B a strong unconformity has been found (Wagner 1955), due to the Asturian phase of the Hercynian orogeny (De Sitter 1957). Between Stephanian B-C and the Permo-Triassic we find another unconformity. The Upper Carboniferous is considered as an intramontane basin sediment in which various characteristic sequences of layers can be distinguished in cyclothemes (Nederlof, 1959).

Permo-Triassic

The Permo-Triassic surrounds the Palaeozoic mountain core on its eastern and southeastern borders. It reaches farthest to the west on the top of the Peña Labra (2018) and as far as Ligüerzana in the Pisuerga valley. A vast area east of the line P. Labra-Valdecebollas-Brañosera-Cillamayor consists of this Permo-Triassic material. From Cillamayor towards the west it lies in a narrow belt along the southern border of the older Palaeozoic.

The Permo-Triassic consists mainly of conglomerates with a high quartz content, red sandstones and mudstones, and marls.

According to Ciry the finer grained sediments (psammites and shales) are well developed in the upper part of the formation, and the conglomerates and the coarser sandstones occur most frequently at the base, but this is not evident everywhere. Locally volcanic elements occur in the sediment, mainly near the bottom. Ciry considers the Permo-Triassic as a detritical series, deposited around the eroded Hercynian Mountains, since the beginning of Permian times up to the Lower or Middle Triassic. The beginning of the sedimentation coincided with post Hercynian volcanism.

Muschelkalk is not present in our region.

Keuper shows a marly and clayey facies, often reddish, sometimes green or gray, with on top a cavernous dolomite. In the marls gypsum occurs rather frequently, which has been worked at various places. Ophites are also present in the Keuper sediments.

The Keuper occurs (1) in a rather narrow belt, east and south of the Permo-Triassic zone; (2) in a zone between Nestar and Aguilar; (3) in the "Pays Plissé" near Barrio Sta Maria.

Jurassic

Jurassic sediments occur in a belt around the Keuper deposits, which surround the Permo-Triassic zone to the east; further in the "Pays Plissé" south of the Sierra del Brezo, and in the region north and south of Aguilar de Campóo.

Near the base of the Jurassic massive or platy limestones are found, generally rather dark in colour. They are followed by a thin series consisting of marly limestones, blue-grey marls and all transitions between them. The third series is a group of white limestones.

Cretaceous

Lower Cretaceous in Wealden facies occurs in the southern part of the region and east of Quintanilla de las Torres and Aguilar de Campóo. Ciry (1939) gives an extensive subdivision of these sediments, which for briefness' sake will be indicated as Wealden in this paper. The main subdivisions are:

Lower group: conglomerates, clays in various vivid colours, subordinate sandstones ("grès") and lacustrine limestones.

Upper group: consisting practically of sandstones, "depôts grèseux"; clays are rare. The coarser sandstones are dominant. Sometimes the Lower group is absent, due to an erosion phase which took place after a folding phase between both groups.

Upper Cretaceous is only present in a belt extending from Ligüerzana to the SE, and in a narrow belt along the southern edge of the Sierra del Brezo. The Upper Cretaceous consists mainly of sandstones, marls and limestones. As it has little significance in our region we shall not give more details.

Tertiary

Tertiary sediments are nearly absent in our area. Sediments of this age are only present in a small region west of Barrio San Pedro, and this is an outlyer of the Meseta Tertiary. Farther southward on the Old Castilian Meseta it covers extensive areas.

Tertiary times have been very important for the morphogenesis of the Cantabrian Mountains, both tectonical and climatic conditions of that time having influenced the present relief.

Structure

We mentioned the two principal phases of the Hercynian orogenesis. In the Pisuerga region these two main phases have an entirely different strike. Structures of the Curavacas phase (Sudetic phase after Stille) all have an E—W trend; those of the Asturian phase (locally named: Peña Cilda Phase, after De Sitter) a NNW—SSE trend.

The Tertiary diastrophism, which is reflected mainly by the narrow, steeply dipping Mesozoic belt along the southern edge of the Palaeozoic mountain core also has an E—W strike. The same trend is found in the southward dip of the Triassic from the Valdecebollas downward, and in the Triassic Reinosa syncline (De Sitter 1957). Moreover the valley of the Rio Castillería is perhaps the site of a shallow syncline of post Hercynian age, with an E—W strike, which would be a continuation of the southward dipping Triassic of the Valdecebollas.

In the Cretaceous sediments SE of Cervera, a pronounced NW-SE trend of folds and faults has been found. This folded zone ("Pays Plissé" after Ciry) is considered by De Sitter as the direct continuation of the Iberic folded chain farther to the SE. The origin of these folds probably should be placed in the Pyrenean phase. The origin of the deformations with an E—W trend, and the steep dip of the Mesozoic sediments along the southern border of the mountain core was found at some places (Castillon) to be of intra Miocene (Savic) age. At other places, for instance in the Reinosa syncline and the Valdecebollas Triassic with its southward dip, no exact dating could be given. Thus, one Hercynian and one Tertiary phase show the same strike; the folds in the Iberic direction find a counterpart in the folding of the Peñas Negras.

The structure of the Mesozoic and Tertiary deposits have been discussed extensively by Ciry (1939). Besides a number of epeirogenetic movements during the whole of the Mesozoic, he distinguishes an Old-Kimmeric phase; a local folding before and during the Lower Cretaceous, and the Tertiary movements. Along the southern border of the Asturian massif he presumes a southward movement by which the Cretaceous sediments obtained their steep and even overturned positions. Also in Ciry's "Pays Plissé" a northern part also has been thrusted over the southwestern part of the zone.

Llopis Llado (1955) considers the Asturian Mountains as a "mega anticline" (updoming), originated in Tertiary times, which was divided up into several blocks by large E—W running faults. His investigations, however, deal with the more western part of the Asturian Mountains.

This summary of the geological features of our region is necessarily very incomplete. For full information the reader is referred to the cited authors. The Quaternary will be discussed later on.

Map 2, which gives a survey on the geology of the region, has been drawn after maps published by De Sitter, Ciry and Karrenberg.

CHAPTER III

WEATHERING AND SLOPE FORMATION IN VARIOUS ROCK TYPES

In this chapter we shall consider the influence of weathering and mass wasting on the various rock types. These two processes and the length of time during which they were active, are among the most important factors determining the denudation slope profiles *). With slope development is meant, of course, a development under the sole influence of weathering and denudation, free from recent erosive influence.

A good deal of theoretical studies has been published on this subject (Lehmann, 1933; Bakker & Le Heux, 1946, 1947, 1950, 1952; Van Dijk & Le Heux, 1952; Looman, 1956; Premier rapport de la Commission pour l'Étude des Versants, 1956, etc.). Practical studies are, in general, only in a preliminary stage, though some important results have been published (Pouquet, Linton, and others in Prem. Rapp. Comm. Ét. Vers.). Great differences in methods exist, partly caused by the different scopes of the investigtaions. In general, large numbers of measurements are required, and these demand a long time. We have made only a few of such measurements so that at present no results of general importance are available, and more data still have to be obtained. So we have confined ourselves in this chapter to mentioning some characteristic slope types on the different rocks (fig. 5 A, B and C).

The best developed denudation slopes ("Richter" slopes, cf. Richter, 1901; Bakker & Le Heux 1952) occur, of course, in the higher and the more upstream regions, in general on those parts where erosive incision is not active. We may expect that the measured slopes, which are all situated in such regions, have been exposed to a periglacial climate during several times in the Pleistocene. As in general the slopes are much older than the Pleistocene, a certain persistence of slope forms seems to exist. Indeed in a number of cases the factors α, β, and c **) can be subject to considerable change during a slope recession process, without a notable change of the slope (Bakker, personal communication). Therefore in many cases the pre-Pleistocene slope type will still be dominant, though altered by Pleistocene slope transformation processes.

We shall now consider the most important relief forming rock types.

Limestones

Caliza de Montaña. — This is the limestone of which the Sierra del Brezo is built up and which occurs in patches in the region east of Cervera. It is a very homogeneous limestone. Screes are strikingly scarce in the Sierra del Brezo, on the mountain slopes as well as in the river beds. It should be

*) Denudation slope = "Denudationsböschung" in the sense of LEHMANN (1933).

**) In the theory on slope formation, put forward by LEHMANN (1933) and expanded by BAKKER & LE HEUX and VAN DIJK & LE HEUX, the factor α stands for the slope angle of the screes at the foot of the denudation slope, β is the slope angle of the initial wall, and c is a constant.

noted that pebbles from this limestone do not occur in the terrace gravel lying at its foot, and that it is absent in all of the Pisuerga sediments. Only along the southern border of the chain, fans and a piedmont alluvial plain (Kanis 1955) occur. These consist of limestone breccias with a calcareous matrix. Kanis ascribes them to Pleisocene pluvial times, at least the plain. To our opinion it is more probable that the plain, formed by the flat breccia fans, is a counterpart of the rañas and belongs to the lower Villafranchian.

Slope profiles in the Sierra del Brezo are very characteristic. The most outstanding type is a rectilinear slope with a rounded top (rectilinear, of course, in a macro-morphological sense). Where erosion becomes active, the slope profile is, naturally, interrupted. The most fully developed denudation slopes have angles between 25° and 30° (fig. 5 B, 2 and 3, and fig. 16, Chapter V), and are developed approximately as "Richter" slopes.

In the region east of Cervera de Pisuerga, the Caliza de Montaña is found as isolated cliffs in shale and sandstone areas. Due to its greater resistance it forms isolated peaks on which no denudation slopes came to a development. It might be expected that karst phenomena should be very intensive in this Caliza de Montaña but we have, in the part investigated by us, not found many indications of solution phenomena. It is still ony of the unsolved problems of this region why these phenomena are not better developed.

Other Palaezoic limestones. — These mostly occur as layers in softer rocks, and form more or less pronounced tops and ridges. Slopes are very irregular at the smaller ridges, the greater ones (Sierra Corisa) at some places show better developed denudation slope types.

Jurassic and Wealden limestones. — These limestones have a reaction different from that of the Palaeozoic limestones. They are less homogeneous than the Caliza de Montaña, and folded in a different and less intensive way. These limestones have been found as pebbles on several terraces. Sometimes faults are important in the relief, e. g. in the region of Barrio de Santa Maria. Karst phenomena are better developed than in the Caliza de Montaña, especially in regions where the limestone layers have considerable thickness, as in the Las Tuerces region south of Aguilar de Campóo. The slope forming properties of these limestones are similar to those of the Cretaceous limestones.

Cretaceous limestones (Cenomanian-Maastrichtian). — Cretaceous limestones are, besides of the Wealden region found in a belt extending south of Vado and Ligüerzana, and in the Las Tuerces region. In the former region, slopes are of various types, the most characteristic one being found east of Dehesa. The limestones form thin banks, often separated by less resistant layers. Consequently there is a strong contrast between low-angle slopes more or less parallel to the bedding, sometimes being real dipslopes, and slopes cutting through the stratification, so that each resistant limestone layer forms a low perpendicular cliff. The mesa effect of more resistant layers, as described by Bakker & Le Heux (1952), is clearly demonstrated here.

Traces of planation may be recognized locally. But the area of Cretaceous limestones is of too small extension to follow these planation traces over considerable distances. Karst phenomena are poorly developed in those regions where a rapid alternation of soluble and less soluble strata occurs. In the Las Tuerces region the limestone layers are more compact and of greater thickness, and here the slope forms are largely influenced by karst processes.

Conglomerates

Curavacas conglomerate. — The Curavacas conglomerate is a very thick deposit of Westphalian B age, thinning out towards the East. It consists of very coarse quartzite pebbles, cobbles and boulders in a sandy and clayey matrix.

As a reaction to weathering, the matrix loosens and the pebbles are set free (fig. 4). Dependent on the topographical position of the outcrop, the freed pebbles are transported downslope slower or faster; in the latter case they break often. In situ these pebbles are very well rounded, and later on we shall meet these pebbles again in the Pisuerga terrace sediments, downstream of the outcrops of the conglomerate.

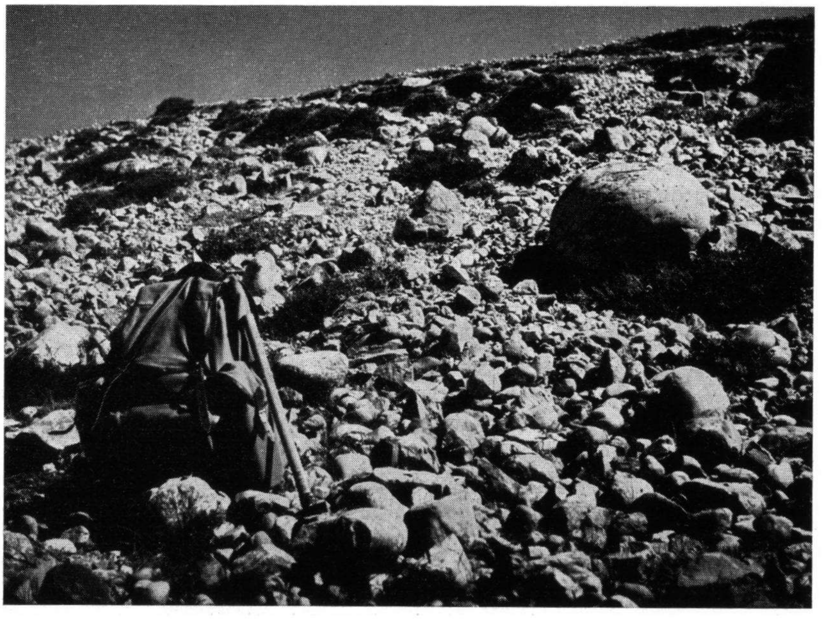


Fig. 4. Weathering of Curavacas conglomerate.

Denudation slopes, freely developed without gully erosion influences, show great variations in slope angles but it is noteworthy that the transitions to other slope angles are always gradual and no abrupt changes of angle occur. The summit level of the conglomerate has locally been affected by glacial erosion during the Pleistocene (as on Mt Curavacas)which gives rise to deep cirques and sharp edges and peaks.

Triassic. — Triassic conglomerates are much finer grained and more compact than those of the Carboniferous. The pebbles are embedded in a more or less sandy matrix and consist for a considerable part of white quartz with minor amounts of variegated quartzitic pebbles. The conglomerate is so compact that the weathering mainly attacks along joints, so that blocks consisting of Triassic conglomerate are set free and are transported downslope. The conglomerate, thus, reacts as a unit and the pebbles are *not* loosened individually. The same applies to the sand grains of the Triassic sandstones.

So the rivers which originate in Triassic regions transport pebbles consisting of Triassic conglomerate and/or sandstone. During the transport and especially after the deposition, weathering gradually attacks them and then at last the pebbles, mainly quartz and quartzites, are set free. But this takes a very long time.

In periglacial climate the weathering of the Triassic rocks must have been much stronger than it is now because of the intensive frost weathering.

Denudation slopes in the Triassic rocks can have various angles, more or less homogeneous rectilinear or slightly convex profiles are found. (Sierra de Hijar, Valdecebollas, etc.). Some illustrations may give an impression of the great variety of slope types in the Triassic (fig. 5 C). It should be noted

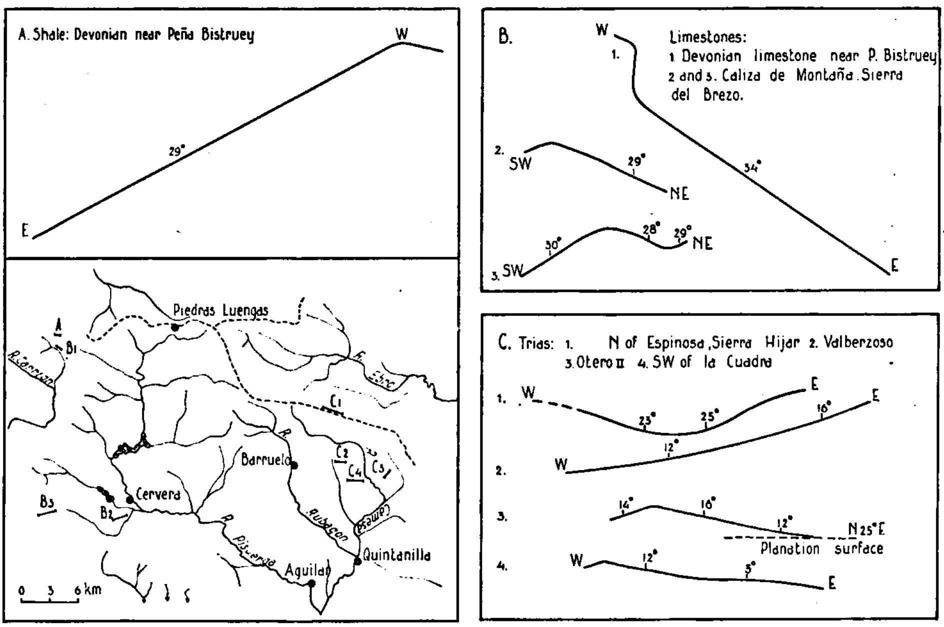


Fig. 5. Slopes in various rock types. For scales compare the map.

that the Triassic does not only consist of conglomerates but of alternations of sandstone and conglomerate layers. At many places the Triassic nevertheless reacts as a morphological unit, that is to say, as pseudo homogeneous material especially with respect to slope formation.

Wealden. — Wealden conglomerates contain ever higher amounts of quartz than Triassic conglomerates. Weathering causes a rapid loosening of all components and the result is unconsolidated sand and gravel. Therefore no pebbles, consisting themselves of Wealden conglomerate, can be formed, whereas pebbles consisting of Triassic conglomerate are frequently met with. A confusion of them, thus, is fully excluded.

Shales

Shales occur mainly in the Palaeozoic, especially in Carboniferous deposits. They are soft and easy-weathering; in the first stages they weather to brittle and flaky fragments which, after further desintegration, form weathering-clays.

But at present soil erosion is so active that the greater part of the weathering products is carried off very rapidly. Only more or less flat parts are covered with a layer of weathering-clays. The grain size of weathering-products of Carboniferous shales (north of Mudá) is presented in fig. 6.

As erosion, especially soil erosion, is very active in the shale area, well developed denudation slopes are mostly lacking. But in the Devonian area, near the main Atlantic divide, some well developed "Richter slopes" are present, an illustration of which is given in fig. 5. Because of the softness of the shales, they are rare; some beautiful slope profiles in shales are found in outcrops where resistant limestone layers overlie a shale bed.

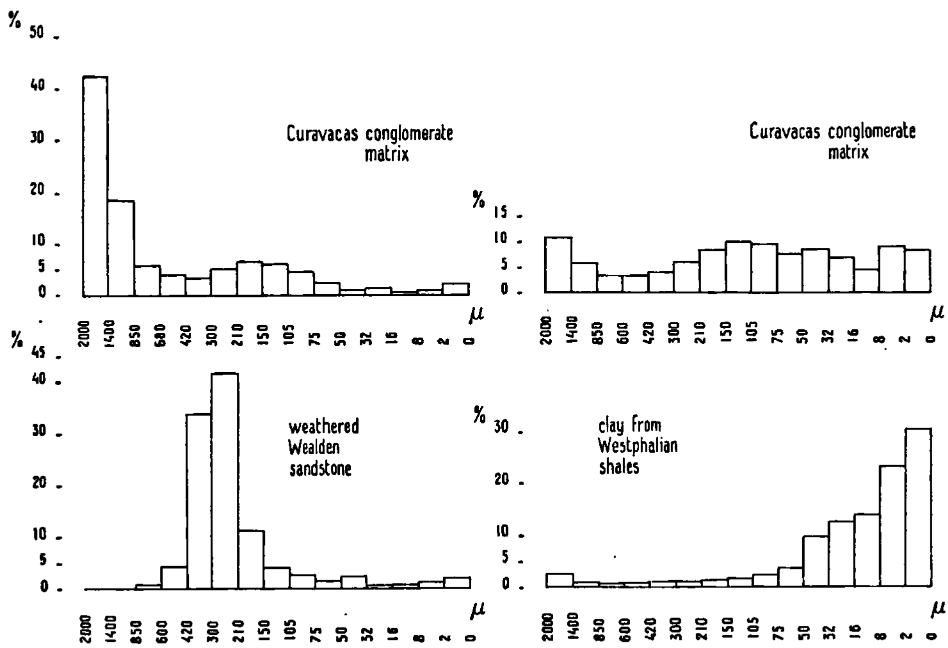


Fig. 6. Grain size distribution of some weathering-products.

Sandstones

Carboniferous sandstones mostly occur intercalated in shale formations as rather thin beds of little thickness. In those cases the whole complex reacts as a unit. When the sandstone layers are somewhat thicker they form local interruptions in the slope profile.

On weathering the sandstones react by the formation of coarse angular stones and blocks, which can desintegrate so as to form a weathering-sand. But in the Palaeozoic region sandstone layers of considerable thickness are rare, and accordingly weathering-sands are nearly absent. Soil erosion rapidly carries of the greater part of the sand formed, thus making their occurrence still rarer.

Triassic sandstones are mainly coarse and resistant. They occur mostly in banks alternating with the conglomerates, and they weather in the same way as has been described for the Triassic conglomerates in the preceding paragraph:

blocks are formed which sooner or later become pebbles in the river beds. Prolonged weathering results in the formation of sand, which is very badly sorted. Slope types in the Triassic were discussed already in the paragraph on Triassic conglomerates.

Wealden sandstones weather very easily to loose sand. The properties of the sand are represented in fig. 6 and 7. From its high degree of sorting, and from the frosted surface and the roundness of the quartz grains, we conclude that this sandstone originally was deposited as an eolian sediment. The grains are completely worn, and weathering afterwards considerably enlarged the pits.

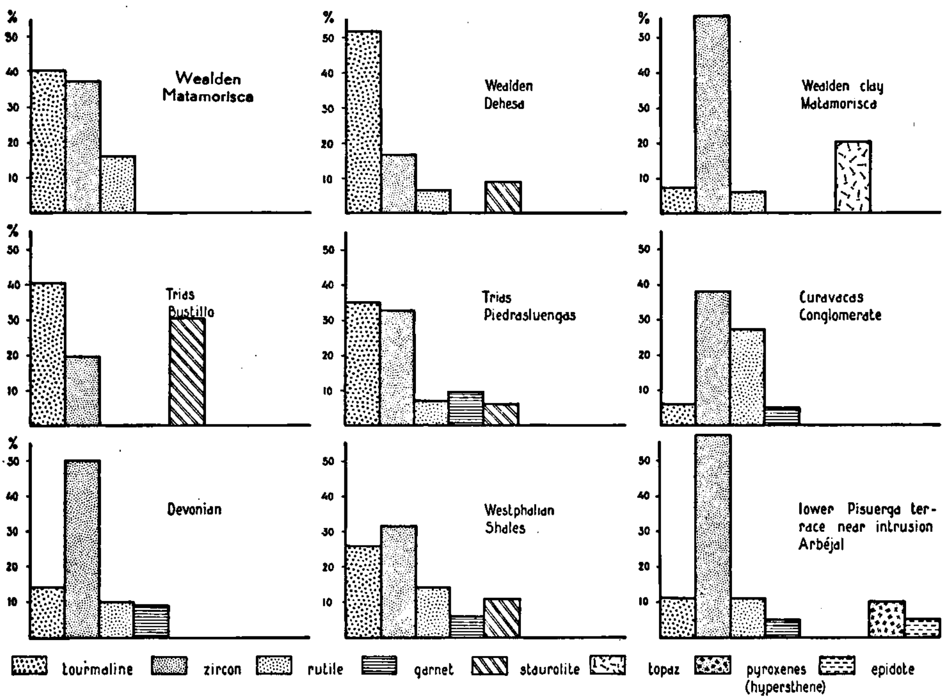


Fig. 7. Heavy mineral composition of weathered rocks; only minerals occurring in 5 % or more are represented.

Heavy mineral associations of some weathering products

In fig. 7 a comparison is made of the heavy mineral associations of some of the weathering products. In view of the foreland sedimentation (Mabesoone, 1959) it is important to know the mineral associations supplied at present by the mountain region. Apart from the tourmaline-zircon-rutile group, which is largely dominant, only garnet and staurolite are of some importance. All other minerals occur in quantities less than 5 %, or do not occur at all. Staurolite is principally provided by the Triassic, and small amounts of hypersthene are supplied by the intrusive rocks; in their aureoles some metamorphic minerals may be expected in the weathering products, but these are only of local importance. Some epidote is found, too. Important quantities of topaz are found in some Wealden samples and also in the vally of the Rubagón, where they have been deposited as a result of periglacial action (cf. Chapter VIII); these are the only ocurrences of topaz in our region.

Other minerals are present in very small quantites. Among them, corundum is the most conspicuous. More detailed descriptions of the shapes of the minerals are given in Chapter VI.

Palaeozoic formations supply almost only tourmaline, zircon, rutile (anatase) and some garnet. Hercynian metamorphism, if present at all, is not reflected in the heavy mineral associations.

CHAPTER IV

GLACIAL AND PERIGLACIAL PHENOMENA

Glacial phenomena in our region were studied extensively by F. Hernandez Pacheco (1944). For that reason we shall not discuss here the subjects investigated by this author; only a brief review of the results so far as they are important to us, will follow.

Periglacial phenomena are found in many parts of the region, and they have not been described as yet. From their widespread occurrence we can conclude that all of our region has been submitted to a periglacial climate during one or perhaps more periods of the Pleistocene. The periglacial relief forms, observed nowadays, may be looked upon as a result of the last glacial phase, which possibly corresponds to the Würm glaciation.

Glacial phenomena

Glacial landscape forms have been known a long time in the Cantabrian Mountains. In 1852, Prado published a study on erratic blocks. Later studies were carried out by Obermayer in 1914, who investigated the glaciers of the Picos de Europa, by Stickel (1929), Vosseler (1931) and others. Their studies concerned mostly the central and western parts of the Cantabrian Mountains. In 1944 F. Hernandez Pacheco investigated the glacial forms of the Montañas de Reinosa which for a part fall within our region. The mapping of those phenomena, so far as they are situated within our region, proved to have been carried out very correctly (fig. 8). We shall summarize the glacial morphology here very briefly.

On the northwestern slope of the Valdecebollas, a complicated cirque basin is found, which, on further consideration, proves to consist of three superposed cirque steps. In the higher the R. Pisuerga originates. The highest cirque above 1900 m is broad and shallow, and situated in the Triassic. The second level is called Sel de la Fuente, and has a mean height of 1850 m; the third lies at a mean level of 1760 m. Here, a deep cave is present in Carboniferous limestones, through which pass the waters of the Rio Pisuerga. It is called Covarrés and lies at 1750 m.

Terminal moraines have been found in the two lower basins, whereas in the highest only ground moraines and recession moraines were found. Outside of the lowest basin, a fluvioglacial fan can be distinguished, which comes down to 1630—1650 m.

The Rio Castillería rises on the *southern slope* of the Valdecebollas in a basin which is obviously a glacial cirque, lying between 1600 and 1850 m altitude (fig. 9).

In the *source region of the Rio Rubagón* three well-developed cirques are present. The westernmost basin presents two clearly marked steps; the central basin is developed as a single, relatively shallow cirque, whereas the northern one is longer, and situated on the southern slope of the Sierra Hijar.

The lowest moraine deposits in the northern basin (Canal de Brañosera, cf. fig. 8) have been found by Hernandez Pacheco at 1430—1440 m; another moraine belt, obviously a lateral moraine, is present as a ridge between 1470 and 1710 m. The central basin has its lowest moraines at 1450 m, the southern at 1680 m. Other moraine belts are present at higher levels.

Further glacial landscape forms have been observed on the Sierra de Peña Labra, and on the Peña Rubia (Sierra Hijar).

As for the moraines, Hernandez Pacheco considered the lowest to be of

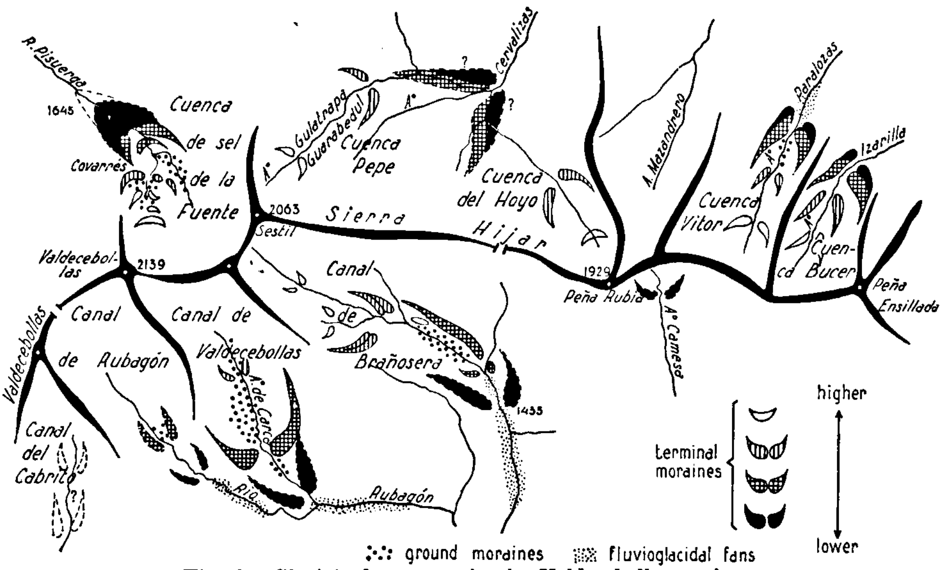


Fig. 8. Glacial phenomena in the Valdecebollas region. Modified after F. Hernandez Pacheco.

Mindel age, the higher ones as Riss moraines, and still higher, he thought to find the Würm moraines, and finally, recession moraines. It is true, generally speaking, that of every group of moraines the lowest is the oldest. It has been preserved because never after its deposition the glacier came so far down as to pass over the moraine belt and destroy it.

The same can be said for a next higher moraine, which is older than any

Fig. 9. Glacial cirque on the southern slope of Cueto.

moraine above it. This does not mean, however, that all glacial stages should be represented by moraines because by destruction of one moraine belt by a younger glacier, the chronological sequence of moraine belts is disturbed. Though we have not carried out extensive investigations of the glacial phenomena of our region, it seems doubtful if from the presence of three moraine belts above each other one might conclude to three glaciations of Mindel, Riss and Würm age, respectively. Moreover, thus far at most two, and at many places only one glaciation have been recognized in Spain. In the Picos de Europa, the highest part of the Asturian Mountains (over 2500 m), two glaciations were recorded by Obermaier (1921). Therefore, too, it seems rather improbable that in the Valdecebollas region, situated some 500 m lower, three glaciations should have occurred.

In our opinion it seems probable indeed that the moraine deposits are all from the last glaciation in the Cantabrian Mountains, and that a number of advances and recessions of the glacier are represented by various moraine belts. The cirque basins might very well be older and have originated in an earlier glacial, to be re-occupied by a younger glacier during the last Würm glacial.

Fig. 10. Triassic block transported downslope by solifluction; height about 4 m, length 9 m. Drawn after a photograph by W. F. H. Pilaar.

Periglacial phenomena

Since moraine belts are found at altitudes of 1500 m and even less, and our region is situated mostly above 1000 m, it is clear that periglacial phenomena can be expected all over the area investigated by us. The most striking features of periglacial action are the huge *blocks* weighing several tons which are found everywhere around the glaciated zone. Where they are grouped along the valleys they may be considered, at least partly, as fluvioglacial blocks.

A good example is found north of Herreruela de Castillería, on the western slope of the Valdecebollas, where a weakly inclined more or less flat-topped ridge, is strewn with such blocks (fig. 10). These blocks, consisting of Triassic conglomerate, are allochthonous, for the ridge is built up of Carboniferous rock. It is hardly believable that they should have been transported in an other way than by moving slowly downslope over a permanently frozen subsoil. If a rock slide would have transported them downslope, they would have broken up, and furthermore, their present position, separated from the most nearby Triassic by a valley, cannot be explained by assuming a rock slide. Downweathering of the Carboniferous shales on which the Triassic blocks should have remained in situ as remnants of a former cover of Triassic deposits, is not probable because of the great height difference between the blocks and the presumed Triassic cover. But moving downslope along a gently inclined surface with frozen subsoil can be imagined very well. It is probable that the flat-topped ridge, by then, was broader and made part of a denudation slope which inclined down to the Rio Castillería, which at that time lay at about 100 m over its present level. The gullies and ravines, at present dissecting the surface, must still have been absent at that time. At many other places north of Herreruela, and in the whole investigated area, similar slopes covered with blocks of large dimensions, were observed.

Periglacial phenomena are further mainly resticted to *"Dellen"* (Schmitthenner, 1926). It is noteworthy that Schmitthenner already thought of the dellen as a possible result of periglacial actions. These dellen can best be characterized as dry shallow valleys. Valleys like these are quite numerous all over the region, though considerable differences in shape occur. The lengths vary from some 50 m to several kilometres whereas the transverse profiles in general are concave at the bottom and convex at the upper ends of the slopes. Often several branches are present. Another delle type is found which is flatter at the bottom than the one just described. But more detailed inspection makes clear, that the "bottom" is not flat but inclined with gentle, concave slopes towards the centre of the valley; a valley floor in the ordinary sense is absent, and the material proved to have been supplied laterally.

So we can distinguish two principal types:

a *Hammock type* (fig. 11) which is called so because of its characteristic hammock-like shape and the properties of which were mentioned above: absence of a valley floor, concave/convex slope profiles; and

a *Flat-floor type* (fig. 12). Here we find a more or less pronounced valley floor which, as we saw, gently inclines to the centre of the valley, and which is built up of laterally supplied material.

We have not represented the occurence of the dellen on a map because this would only be possible on a large-scale map, and our region is too extended to do so.

Some of the "flat floor" dellen at present carry brooklets during part of the year, mainly in spring after snow melting, and in periods with heavy rainfall. Some deformation of the original periglacial profile may have been caused, thus, by gully erosion, but according to Schmitthenner this is no objection for considering them as dellen (see also Jungerius, 1959). Both of the types occur all over the region, though the hammock dellen mostly occur on higher plateaus such as the fluviatile terraces, and planation surfaces, and the flat floor dellen, of larger dimensions, often form the transitions to normal erosion valleys. They are best developed in the upper Camesa region, northwest of Quintanilla and around Mataporquera. The dellen of this type in this region are broad up to their most upstream ends, which are mostly formed by low valley-divides. The "floor" consists of angular rock fragments from the slopes of the valley, embedded in finer colluvial material; together with its gentle concave inclination towards the centre of the valley (5° to 2° or 1½°)

Fig. 11. Hammock-delle near Matalbaniega.

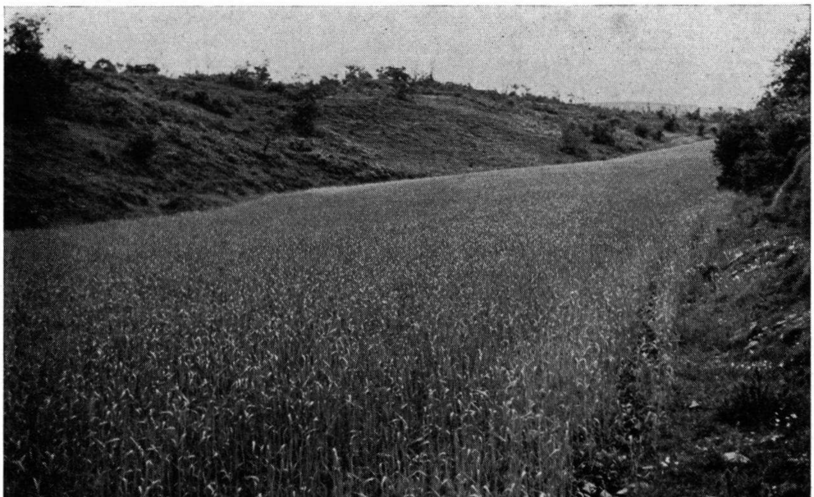


Fig. 12. Delle in the Rubagón area. Bottom widened and flattened by human action.

this demonstrates clearly the lateral supply of the bottom sediment. The hammock dellen also contain colluvial deposits. Their thickness could not be measured, but it is estimated as not exceeding a few metres. The slopes in many cases consist of bare rock, free from any screes.

Solifluction and soil creep are widespread phenomena. Especially on terrace slopes we find the gravel and boulders transported downslope over considerable distances, so that the area occupied by terrace sediment is much greater than the actual terrace surface. Even occur "terraces" which are only the roundtopped remnants of an original terrace, while the slopes are covered with gravel down to far below the original surface. In other formations, these phenomena are present to the same extent but less conspicuous, as the difference between the fresh rock and the weathering products, transported downslope, is not so outstanding. Phenomena as "Hakenwerfen" and frost fissures, etc. have not been observed; they are difficult to find because practically no adequate outcrops occur. They will certainly be present.

In the mountainous part of the investigated area, it is very difficult to distinguish exactly which deposits are periglacial and which are recent. We should keep in mind, that winters are long and hard here. An insolation is strong at these latitudes, especially on the southern slope of the chain, we may expect a considerable amount of frost weathering in winter time even now.

At the present time, doubtlessly a certain amount of soil creep is active, which mixes up with the results of periglacial actions. Soil erosion is very active, often in a disastrous way. Remedies to it will be re-afforestation, in which the Spanish government is very active already, and better instructions for the peasants for contour ploughing.

CHAPTER V

DESCRIPTION OF THE PISUERGA TERRACES

The valley of the Rio Pisuerga is characterized by numerous terraces along its course. In this chapter a description of the individual terrace parts will be given; the reader is invited to compare fig. 13 and map 1 with this description. In Chapter VI the sedimentary petrography of the terraces will be discussed, and besides conclusions on the sedimentation conditions, conclusions on the correlation of the various terrace parts will be drawn. For the sake of readability however we will summarize these conclusions here, and later on the reader will find the arguments which led us to them.

The individual terrace parts can be grouped in the following levels:

HP terrace	relative height:	120—150 m	
LH "	" "	80—100 m	Middle terraces
HM "	" "	50— 55 m	Middle terraces
MM "	" "	about 40 m	Middle terraces
LM "	" "	20— 30 m	Middle terraces
HL "	" "	5— 10 m	Lower terraces
Lower "	" "	up to 5 m	Lower terraces

In the descriptions a number is put behind most of the discussed terrace parts. This corresponds with the numbers indicated in fig. 13. First, wandering in the downstream direction, a brief description of the individual terrace parts will follow.

The HP terrace

The Herreruela terrace part (1) is situated north of the R. Castillería, and is inclined towards the S and W; it forms the continuation of the "Herreruela slope", which was discussed in Chapter IV. The terrace surface is covered with blocks of Triassic conglomerate and has the same inclination as the present river. Its absolute height is 1310—1250 m, that is 110—120 m relative.

This terrace part in our opinion must be considered as a part of the HP terrace level; although its relative height is a little lower, the relation is very clearly observed in the field. The continuation of the Herreruela terrace part can be followed over the San Felices (2) and Vañes terrace parts to Polentinos, as will be seen further on in this paragraph. So this Herreruela terrace part is the most upstream extension of the HC terrace.

The two San Felices terrace parts (2) are separated by a younger valley. Their heights vary between 1240 and 1200 m, which also gives a relative height of 110—120 m. Cover sediments are nearly absent, only some small and one single large Triassic block are found. We consider the terrace parts as remnants of an Old-Pleistocene terrace as will be argued later on (Chapter VI).

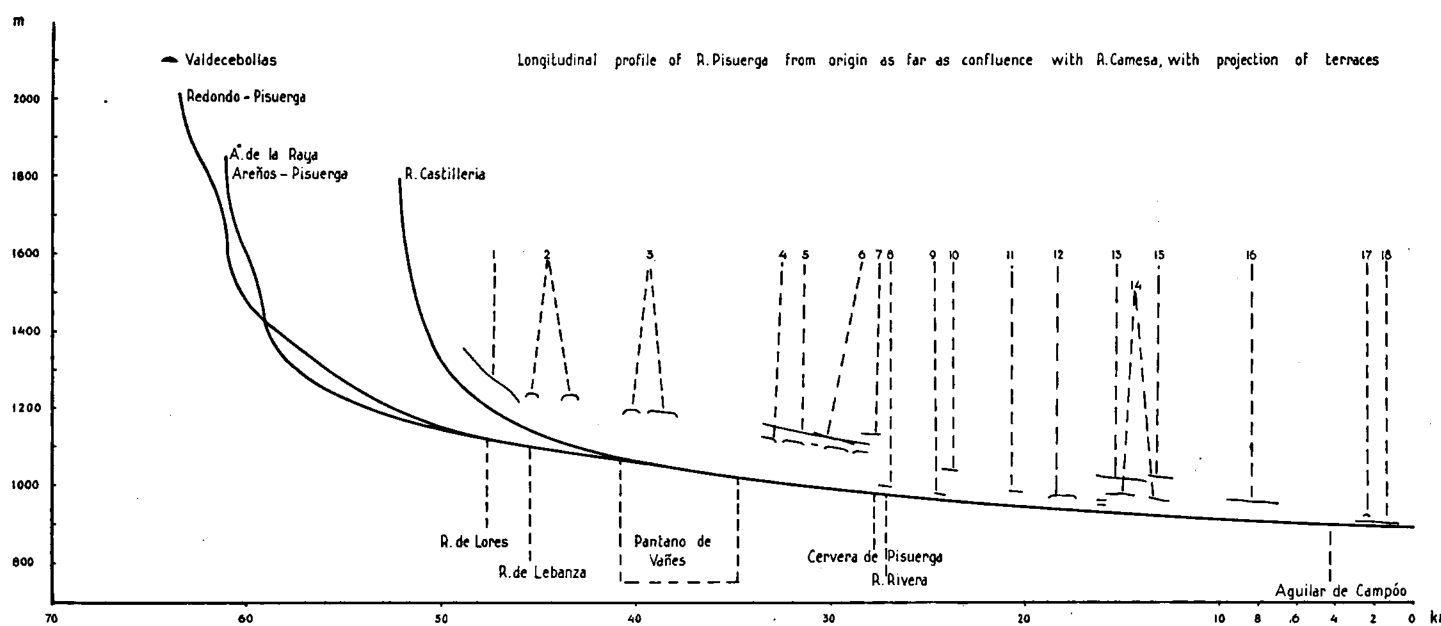

Longitudinal profile of R. Pisuerga from origin as far as confluence with R. Camesa, with projection of terraces
m
2000
1800
1600
1400
1200
1000
800
Valdecebollas
Redondo - Pisuerga
A.º de la Raya
Areños - Pisuerga
R. Castilleria
R. de Lores
R. de Lebanza
Pantano de Vañes
Cervera de Pisuerga
R. Rivera
Aguilar de Campóo
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
70 60 50 40 30 20 10 8 6 4 2 0 km

Fig. 13.

If ever a sediment has been present, it must have disappeared by later erosion; the Triassic blocks we find now most probably were deposited in younger Pleistocene times (cf. Chapter IV).

North of Vañes a possible terrace remnant is found at a relative height of 100—110 m. It is not indicated in the profile of fig. 13, and seems to be only a remainder of the ancient terrace, lowered by erosion.

The Polentinos terrace parts (3) are situated northwest of the Pantano de Vañes. Two parts can be distinguished, both at 1180—1190 m, so at a relative height of 120—130 m. The surfaces are covered with gravel, consisting of a mixture of angular red quartzitic sandstones (local Devonian), rounded reddish and yellow quartzites (Curavacas conglomerate) and some pebbles consisting of Triassic conglomerate. So here we see the first mixing of Triassic and Curavacas gravel, which points to a confluence of two branches of the HP (High Pisuerga) system: one branch from the Triassic escarpment and one from the Curavacas conglomerate region. The thickness of the sediment cannot be given exactly because of lack of outcrops. We estimate it, however, at three metres.

The Cervera terrace part (5) is the most conspicuous of all Pisuerga terraces (fig. 14 and 15). It extends northwest of Cervera de Pisuerga as an enormous flat surface, covered with masses of rounded yellow and reddish quartzite pebbles. On further inspection, the surface is not so flat as it seems to be from some distance; younger gullies partly have dissected it. Two separate terrace parts can be distinguished, a western and an eastern one. Some of the gullies on the terrace surface can easily be recognized as "dellen", most of them are of the hammock type (cf. Chapter IV). On the map the recognizable terrace surface is represented; the pebbles extend over a much greater area because of solifluction and recent soil creep. The thickness of the terrace cover was established as varying between 10 and 14 metres. The height of the terrace part ranges from 1200 m in the west and 1180 m in the north, to about 1130 m in the southernmost part. This means a relative height of 120—150 m above the present valley bottom.

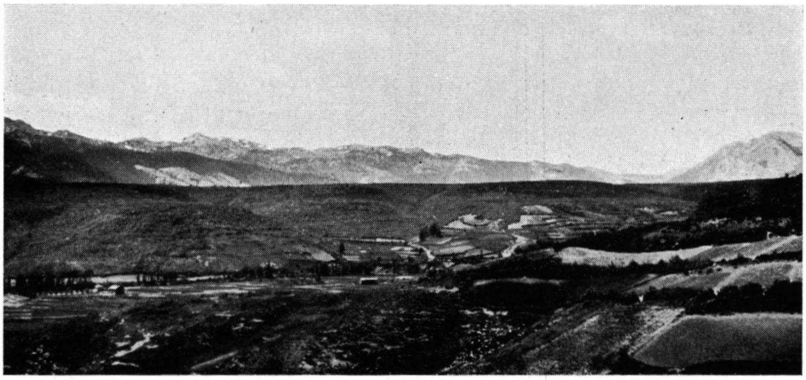
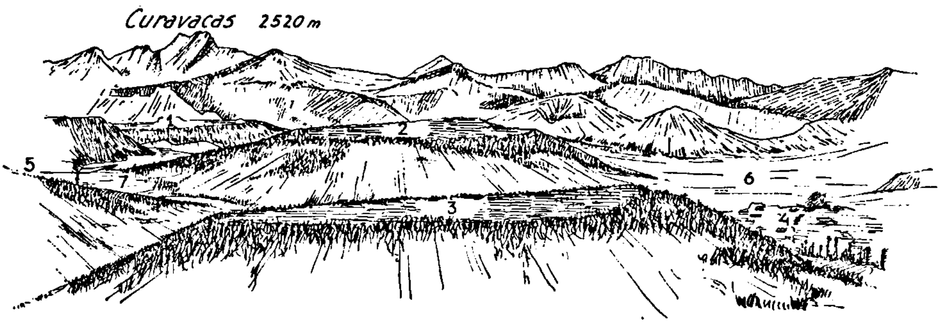


Fig. 14. The HP Cervera terrace part seen to the W.

Below the gravel or perhaps intercalated in the lower part of it, a reddish sediment outcrops at some places. It consists of reddish clayey sand, which shows none of the properties of a soil profile, and must be considered as a bi-phasic *) fluviatile sediment (cf. fig. 24) from the beginning of the HP terrace sedimentation.

On the eastern slope of the terrace, descending to the broad Pisuerga valley, *a second terrace surface* (4) is encountered which makes part of the LH terrace and hence will be discussed in a following paragraph. East of the Pisuerga valley we find the *Rabanal terrace part* (6). It is covered with the same pebbles as the Cervera terrace part, and has a relative height of 120—140 m; its surface is somewhat more inclined than those of the other terrace parts, obviously because of later erosion of its southwestern part. The base of the terrace seems to be less inclined; consequently the sedimentary cover wedges out from NE to SW.

At some distance to the SE, the *Vado terrace part* (7) (fig. 15) rises up as an isolated hill. It has a flat surface, covered with pebbles, at a relative height of 120—130 metres. Southward, separated by a transverse valley, it



1, 2 } Cervera terrace part
3 Vado terrace part
4 Cervera de Pisuerga
5 Pantano de Ruesga
6 R. Pisuerga valley
7 R. Rivera valley

Fig. 15. Looking north from top of Mariserrana.

continues in the *Dehesa terrace part* (7) (fig. 16). The curious situation of this terrace does not show the slightest relation to the present course of the Rio Pisuerga. Its surface lies at about 1130—1140 m, so relative to the river at 130—140 metres. It is covered with the same material as the Cervera terrace part, with a thickness of 10—15 metres.

This terrace is obviously bound to the *"Brezo gate"*, a depression in the southern range between the Mesozoic of the Mariserrana and the Palaeozoic of the Sierra del Brezo (fig. 17). Southward, the terrace becomes broader and less pronounced as the Brezo gate opens towards the wide high plains of the Tertiary Meseta; this part, however, will be discussed by Mabesoone (1959) though we shall have to return on it in a following paragraph.

The LH terrace

The most upstream extension of the LH terrace level is found as a second surface on the eastern slope of the Cervera terrace part (4), as was mentioned previously. Pebbles are absent so that on its surface a hand-boring could be

*) Bi-phasic in the sense of BAKKER & MÜLLER (1957).

carried out; down to a depth of over 1.20 m below surface it showed reddish clayey sand, which on further examination (Chapter VI) could be recognized as the same material which was found below the gravel of the HP terrace surface. From the sediment analyses it appears that the material is not a weathering-product of the underlying Carboniferous shales (cf. Chapter III, fig. 6). It is obviously a fluviatile sediment of a bi-phasic type, which points to a rather quiet sedimentation with seasonal variations, on a valley floor probably covered with some vegetation (Bakker, personal communication). The height of this lower terrace surface is 1080—1100 m, that is 80—100 m relative.

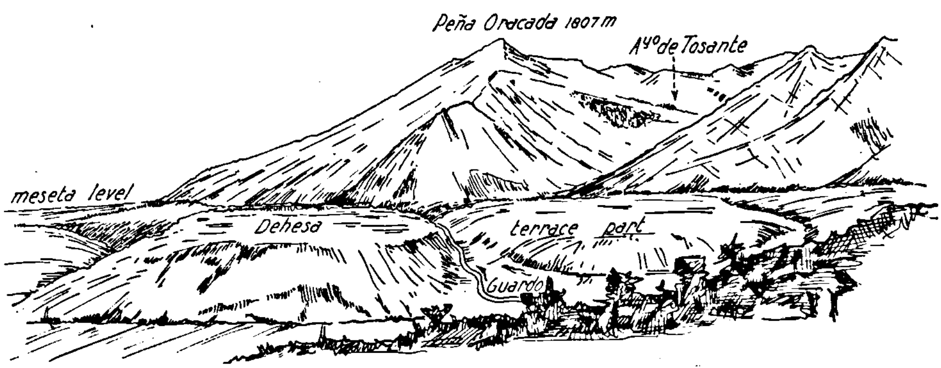


Fig. 16. Dehesa terrace part seen from southern slope of Mariserrana.

Near Ligüerzana on the southern bank of the Pisuerga a terrace remnant is found as a pebble cover upon the more or less rounded top of an isolated hill (10). This pebble cover has a thickness which could be estimated at about 2 metres, and the pebbles are not so abundantly strewn as on the HP terrace parts of Cervera and Dehesa. Because of a bush cover, no outcrops were available for making more detailed observations on thickness and composition

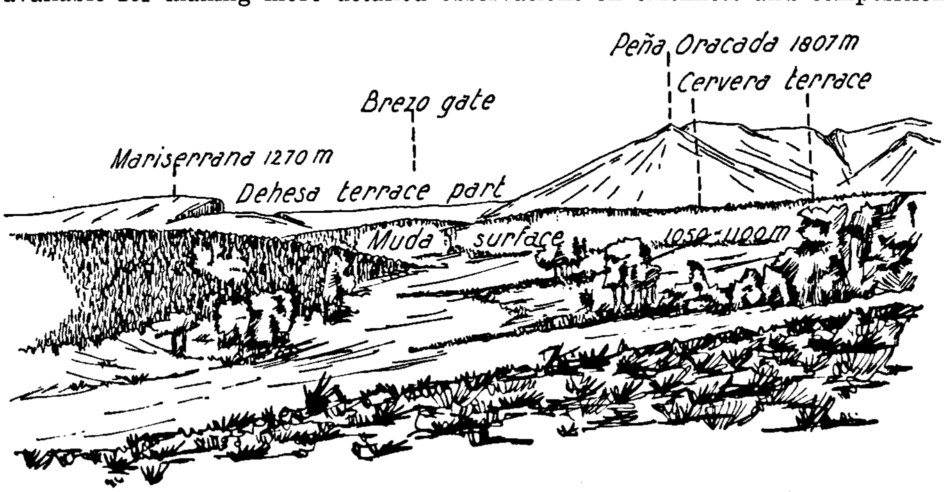


Fig. 17. Brezo gate and Mudá surface seen from the Mudá environs.

of the sediment. Because of the roundness of the top surface we may assume that this terrace remainder has been subject to considerable erosion and solifluction. Its present height is 75—80 m relative so that it can be looked upon as a part of the LH terrace level.

Not far downstream of Salinas, the course of the Pisuerga is on both sides accompanied by terraces. The *Barrio terrace part* (13) lies on the right bank of the river, at a height of about 1030 m, that is at a relative height of 90—100 metres. It needs some search to find here any quartzite pebbles, but they are certainly present, be it that they are hard to find between the shrubs. The thickness of the fluviatile sediment is about 3—4 m.

Opposite, on the eastern bank, we find a counterpart in the *Humín terrace part* (15). This is a flat-topped, gravel-covered hill, at a relative height of also 90—100 m. Equally the gravel cover is less conspicuous than on other terrace parts, and is similar to that of the Barrio terrace part, both in thickness and in scarceness of the pebbles. Undoubtedly, they belong to the same ancient valley floor. At some distance to the North, that is east of Salinas, we find in the same level a remnant of a terrace cover consisting of individual quartzite pebbles loosely strewn over the local calcareous rocks. This must also be a remnant of the same valley floor.

The middle terraces (HM, MM and LM levels)

The HM level. — The *San Mames terrace parts* (14) are situated on the left bank of the river between Salinas and the just mentioned Humín terrace part. Two separate parts, both at a relative height of 50—55 m can be distinguished at little distance of each other. A sedimentary cover, very rich in quartzite pebbles, and about 2 m thick, is present on both terrace parts. As great masses of pebbles have been transported downslope it is difficult to determine exactly the thickness of the sedimentary cover.

The two *Frontada terrace parts* (16) are situated on the right bank near the village of Frontada, about 5 km downstream of the San Mames terrace parts at a relative height of about 50 m. They are separated by a younger valley, and obviously they must be considered as a unit. The extremely flat surface is covered with the characteristic coarse, rounded, quartzitic Pisuerga pebbles, to a thickness of 2—3 m. Here, however, it is mixed up with fine grained quartz gravel supplied by Wealden conglomerate in the surroundings. The situation of this terrace part is rather remarkable as it lies just downstream of a gorge through which the Pisuerga passes with rapids, and on which we shall return later on in this chapter.

The MM level. — On the left bank of the Pisuerga, *about 1 km southeast of Cervera,* a considerable mass of pebbles is found at a relative height of about 40 m. No traces of the former terrace surface could be found; the gravel is spread out on the present slope to the Pisuerga valley. Though a flat surface is lacking, the relative height of the pebbles makes us consider this gravel occurence as a remainder of an MM terrace part.

The *Barcenilla terrace part* (11) is situated on the right bank of the river at about 990 m, that is at a relative height of 40 m. Its surface is covered by pebbles of large dimensions, which are always apparently well-rounded. A detailed description of the sediment will be given in the next chapter. Its thickness is 2—3 m. The terrace surface is strikingly flat; its situation with respect to the valley of Barrio de Sa. Maria is very peculiar, and some remarks on this subject will be made in a following paragraph.

About three km farther downstream, the *Salinas terrace part* (12) is found. This is similar to the Barcenilla terrace part, only it is less well preserved and not so flat as the former. It is also covered with rather rounded quartzite pebbles, to a thickness of about 2 metres. The terrace part also lies at a relative height of 40 m.

The LM level. — At *San Salvador de Cantamuda* a possible terrace surface at a relative height of 20—40 m is found. It is covered with gravel consisting of quartzitic sandstone, badly rounded; its surface clearly inclines towards the present river bed. This inclination may be an indication that we are not dealing with a real terrace surface but with a fossil alluvial cone; just at this place a tributary valley discharges into the Pisuerga valley, and in our opinion the inclined pebble-covered surface has more of the properties of an alluvial fan than of a terrace remnant.

Immediately over *the Rio Rivera valley,* just south of Cervera, at a relative height of 20—30 m, a small terrace remnant is found (8); it can be recognized because of the occurence of quartzite pebbles similar to those of the Cervera terrace part. Undoubtedly it is a remnant of a former terrace part belonging to the 20—30 m level (LM terrace).

A following part of the LM terrace level is found on the right bank of the river, at *Ligüerzana* (9); its relative height is 20—30 m and it lies a little west of the LH terrace part also present here. A thin pebble cover is found, the pebbles being of the same quartzitic type. The thickness of the cover could not be measured exactly because of lack of outcrops; it is estimated at 1½ metres.

In fig. 18 the area occupied by the Pisuerga in the successive terrace-periods is indicated for the region between Barcenilla and Frontada.

Southeast of the Barcenilla terrace part runs the valley of the Arroyo Realista, in which Barrio de Santa Maria is situated. The divide, southeast of the terrace part, between the Arroyo Realista and a brook running to the NW in the direction of Barcenilla, lies at 980 m altitude, whereas the topographical height of the Barcenilla terrace part is 997 m. Nevertheless, in the valley of the Arroyo Realista no Pisuerga sediments are present and it is easily seen in the field that they have never been there. This leads us to the conclusion that in the MM time the divide was considerably higher, and probably also situated somewhat more to the NW, and that since this time it has been subject to a rapid lowering.

The broadness of the Arroyo Realista valley must be considered as a result of the subsequent course of this valley, which is largely determined by the strike of a group of faults (Ciry, 1939) and by the presence of soft rocks.

In front of the San Mames terrace parts, a part of the LM surface can be recognized. Its height is about 20 m relative, and a pebble cover of about 2 m thickness is present. The area occupied by this terrace part is only small.

Finally, *east of Aguilar de Campóo* (17) a terrace remnant is found at a height of 25 m above the present river level. It is no more than a round-topped hill covered with pebbles all over its surface.

The present river passes south of this terrace part, but north of it an extensive occurence of Pisuerga gravel is found at a relative height of 5—10 m, which we call the *HL terrace,* and which only occurs here. The LM terrace part discussed above thus is to be considered as a fossil cut-off meander core.

The Lower Terrace

The Lower Terrace will be discussed as a unit. It is found along the greater part of the present river and reaches far upstream into the mountains. Already here, in the upper parts of the course, the Lower Terrace shows a considerable width, mostly of several hundreds of metres, in which the river meanders; it is situated from 1 to 4 metres above the present river bed. The thickness of the sedimentary cover is here about 2 metres, and the river has cut wholly through it. The sediment consists of unsorted sand and clay with angular and sub-angular pebbles consisting of local Devonian quartzitic sandstones, and some Triassic.

The occurence of Lower Terrace is also indicated on map 1, and the reader will see that even on this 1:100,000-scale map the Lower Terrace appears as a belt of considerable width. The terrace is widest between the Pantano de Vañes and Cervera de Pisuerga, and in the region around Aguilar. Characteristic is that mostly the broader plains of the terrace are bordered at their downstream sides by some resistant ridge through which it is harder for the river to pass. Within the gaps, Lower Terrace is absent or

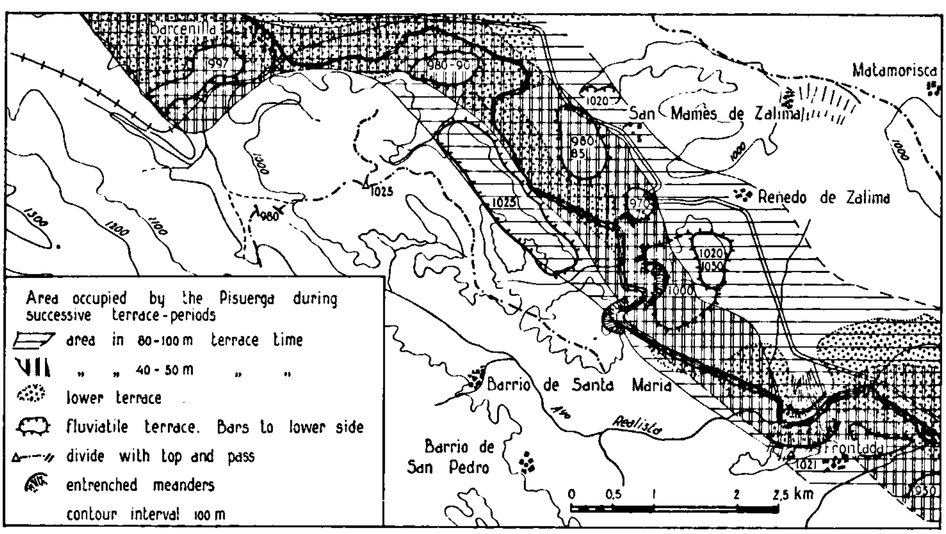


Fig. 18.

very insignificant; upstream of them, the river could develop meanders, thus broadening the valley floor, which after incision became the Lower Terrace.

Along the whole of the river course the Lower Terrace has a relative height not exceeding 5 metres. Only the 5—10 m terrace part near Aguilar, which was mentioned already, forms an exception.

At many places, the Lower Terrace is laterally bordered by denudation slopes with small slope angles, which gradually rise up from the terrace surface; it will be clear that their profiles have largely been influenced by solifluction. This phenomenon of small-angle slopes over a terrace is still more conspicuous with the higher terraces, especially with the HP and LH levels.

A final remark has to be made about the Lower Terrace downstream of

Aguilar. It has a relative height of 1—3 metres, and is extremely wide. From the occurence of quartzite pebbles may be concluded that the terrace has been deposited by the R. Pisuerga and *not* by the Rio Camesa. In HL times, that is in the time of the 5—10 m terrace, the confluence of the rivers Pisuerga and Camesa was situated several kilometres farther to the North than at present, that is straight east of Aguilar, near the railway station. Afterwards, as the Pisuerga shifted to the SW, the terrace was spread out, and the confluence of both rivers shifted southward.

CHAPTER VI

SEDIMENTARY PETROGRAPHY OF THE PISUERGA TERRACES

In this chapter the following sedimentary-petrographical properties of the Pisuerga terraces will be discussed: pebble associations; roundness of quartz pebbles; grain size of the particles $< 2000\ \mu$; roundness of quartz grains of the size range 500—1050 μ and heavy mineral composition.

Though in general we shall discuss the terraces from "high" to "low", the gravel paragraphs will be in the reverse order, from "low" to "high", for the sake of a better demonstration of the influence of the Curavacas conglomerate.

Pebble associations

The gravel composition of the *Lower Terrace* is shown in fig. 19. This and similar diagrams have been so composed that the quartzite content is plotted from the bottom, and next, if present, quartz. The percentages of Triassic material are plotted from the top, then those of the sandstones and finally, if present, those of Mesozoic limestones. A rest group remains between the top group and the bottom group. These diagrams are simplified; in the field many more distinctions were made: in the quartzites according to their colour, the Triassic pebbles after their texture (sandstone or conglomerate), etc. But simplified in this way, the diagram becomes better readable. The distances between the points where the analyses were made, are at scale in this diagram.

We see the content of quartzites increase from some 40 % at San Salvador, to more than 80 % at Arbejal. Here the strong influence of Curavacas conglomerate is obvious; the quartzites of G 29 and G 30 can be recognized as having been supplied by the Devonian. As far as Arbejal (G 40) no suitable outcrops in the Lower Terrace are present, but downstream of Vañes the river passes through the Curavacas conglomerate (cf. map 2). This results in a sudden increase of quartzite; we may expect that the curve connecting the quartzite percentages of G 30 and G 40 in fact runs more horizontally up to $^2/_3$ of the distance, and from there rises very steeply. The bright colours and the roundness of the quartzites are completely different from those of the pebbles of G 29 and G 30, which were recognized as Devonian ones, and which are, generally, darker in colour.

The high sandstone content in the upstream parts can be ascribed to a supply by Devonian and Carboniferous sandstones. A supply from the Triassic is easy to understand as some branches of the river originate in the Triassic region. From G 27 to G 22 the quartzite content slowly increases, though along this part of the river there is no supply of quartzite. As the quartzites are very resistant, this increase can only be a relative one, caused by desintegration of other pebbles. Triassic material is present as far as Salinas; downstream it disappears and is replaced by Mesozoic limestones, through which the river passes in the San Mames region.

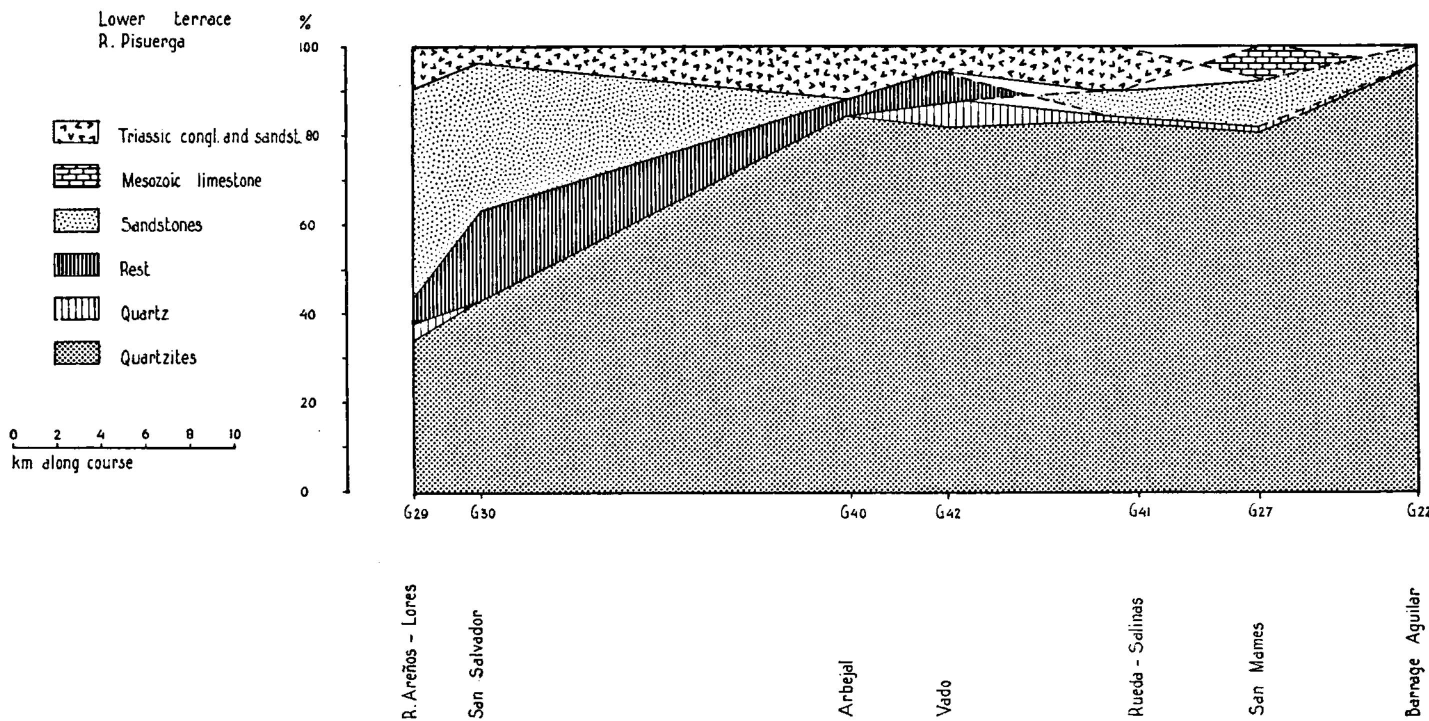


Fig. 19. Gravel composition of the Lower Terrace of the Rio Pisuerga.

It is noteworthy, that Carboniferous limestone (Caliza de Montaña) is completely absent (cf. Chapter III). Though an important tributary of the Pisuerga, the Rio Rivera, originates in the Sierra del Brezo, not a single piece of limestone is found in the Pisuerga sediments.

Fig. 20 B *) represents the gravel composition of the *intermediate terraces* group. The same components as in the Lower Terrace are present, and more or less in the same proportions as well.

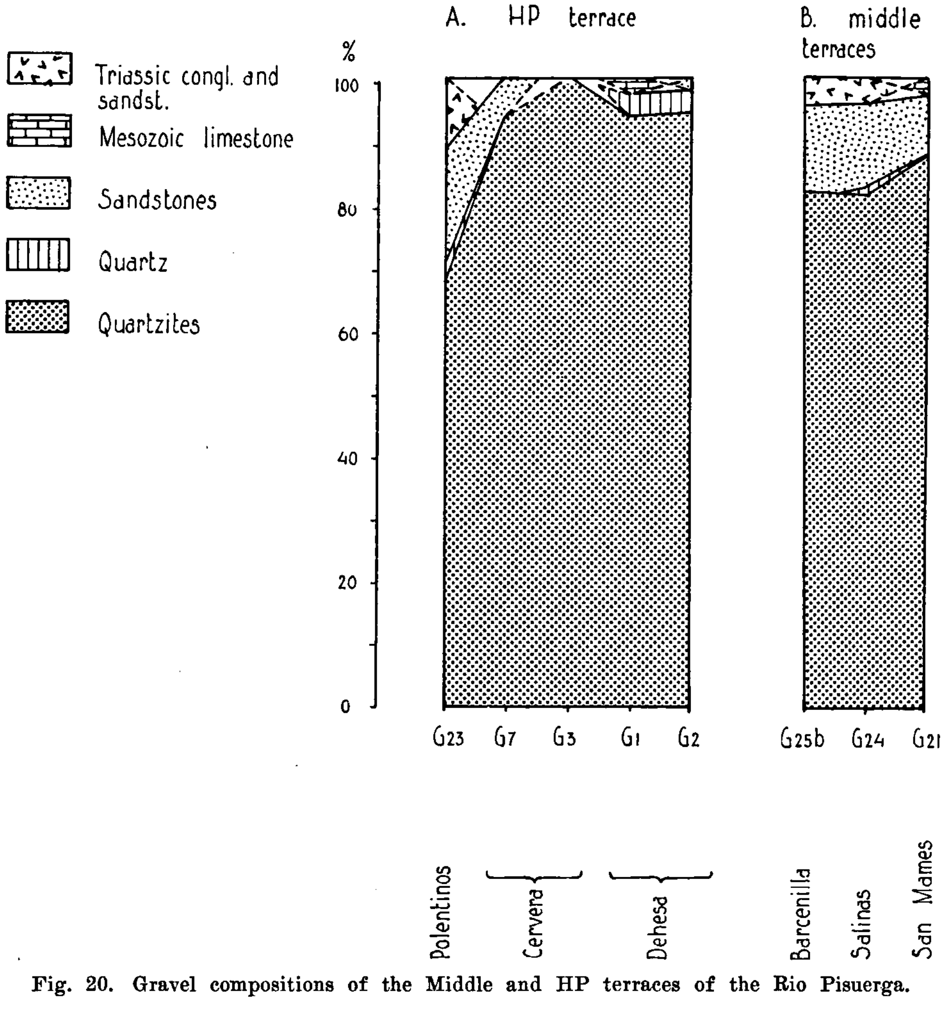


Fig. 20. Gravel compositions of the Middle and HP terraces of the Rio Pisuerga.

Fig. 20 A *) represents the gravel composition of the *HP terrace* taken from the Cervera and Dehesa terrace parts. Some differences may be attributed to different lateral supply. It will be remembered that the Herreruela and San Felices terrace parts do hardly bear any deposits; all the same the small amount of Triassic material found on the Cervera and Dehesa

*) In these figures, the horizontal distances are not at scale.

terrace parts, yet must be ascribed to a supply from this direction. The quartzite percentage is considerably higher than in the middle terraces, and the quartzites are undoubtedly proceeding from the Curavacas conglomerate.

On the Dehesa terrace part, Triassic pebbles occur in quantities of less than 1 %. Nevertheless this occurrence is of the greatest importance, for it is an additional proof of the connection of the Cervera and Dehesa parts, and of the existence of a southward running river at that time.

Regularly the highest percentage of the counted pebbles occurs in the 4—8 cm size interval; less frequently the modal class is 8—16 cm. Specimens with a diameter > 32 cm occur rather frequently, and not seldom some of them exceed even 75 or 100 cm. So the sediment may be characterized as a *pebble and cobble gravel* (Pettijohn, 1957, table 5).

In the downstream direction the mean diameters slowly decrease; supply of new material, such as pebbles from the Curavacas conglomerate, causes a sudden increase in diameter, which from there on decreases again in the downstream direction.

To illustrate that the Curavacas conglomerate indeed fully consists of quartzite pebbles we will give the average of 5 × 100 countings of the pebble composition in table 2.

TABLE 2.

Pebble composition of the Curavacas conglomerate (averaged from 500 specimens in 5 countings).

White-yellow quartzite	47 %
Brownish-yellow „	16 %
Grey „	19 %
Reddish „	6 %
Other brownish „	11 %
Other quartzites	1 %

Pebble roundness

The roundness of pebbles was measured according to the method described in Chapter I. According to Tricart & Schaeffer (1950) roundness measurements should be carried out on one kind of pebbles only. In our region so rich in quartzite pebbles we have, of course, chosen quartzites for such measurements.

In fig. 21 the results are represented graphically by frequency curves *). These diagrams have been so composed that on the horizontal axis the roundness index intervals are plotted in ranges of 100. The percentage of pebbles with roundness indices within such a range, are indicated by a point vertically above the centre of the index interval column. To the left of the Y-axis, a separate column has been erected, in which the percentage of recently broken pebbles is indicated as "rec. fract.". In this column, thus, is plotted the percentage of pebbles showing a fresh rupture plane obtained after recent or subrecent weathering in the outcrop of the terrace. In doing so, we avoid an exaggeration of the percentage of the index interval 0—100; of course the index of the pebbles "rec. fract." equals zero. The percentages plotted in the left column were obtained by considering all pebbles (inclusive the percentage "rec. fract.") until a total amount of 100 % was reached; then

*) In the sketchmap showing the measuring-localities the measurements taken together in one graph are indicated with the same signature.

the measurement was continued on the pebbles not "rec. fract." only, so as to obtain their mutual percentages, totalling also 100 %. The lines connecting the points of the left column with the curves in the graph right of the Y-axis, have no graphical significance and only serve as an indication of the curves to which the percentages plotted in the left column belong.

Fig. 21 A represents the roundness indices of pebbles with a maximal diameter > 4 cm of the *Lower Terrace* of the Pisuerga, whereas those of the Middle and the HP terraces are shown in fig. 21 B and C, respectively *).

Curve 1 (fig. 21 A) represents the most upstream part of the Lower Terrace, N of Areños. We see low roundness values with maxima in the index interval 0—200. Curve 116 is from the Lower Terrace at Arbejal, that is downstream of the Curavacas conglomerate zone (map 2), where the rounding of the pebbles appears to be much better, a considerable amount of pebbles having indices of over 400. This is not due to a better rounding of the Devonian quartzite pebbles from the upstream course, but to a supply of Curavacas conglomerate pebbles, which have a better roundness degree of themselves (fig. 21 C). Their original roundness is reflected in the terrace sediment. The Devonian quartzite pebbles must also be present but their quantity is so small in proportion to the large masses of pebbles supplied by the conglomerate that they become insignificant. Going farther downstream we meet locality 110, the curve of which shows little difference with 116; but still more downstream, near Aguilar, the roundness has again increased, as is seen mainly from the increase of the number of pebbles with indices greater than 300. Obviously this is a case of normal fluviatile rounding during transport, in which a selection of the better rounded pebbles, due to their easier transport, might be involved. The pebbles show a notable fragmentation of the original material (that are the rounded pebbles from the Curavacas conglomerate), followed by a resumption of wearing. Such conditions are generally realised under a cold climate as a result of periglacial actions, mainly frost weathering (Tricart, personal communication). The influence of the original material is still visible in the rather high percentage of indices greater than 400; obviously not all the pebbles have been broken up by frost weathering. The resumption of wearing after the fragmentation is clearly visible in the index interval below 300.

The gravel of the *Middle Terraces* is considerably less rounded (fig. 21 B). Curve 112 only is not from the Middle Terraces but from the LH terrace remnant at Ligüerzana. The three curves of the Middle Terraces are very similar to each other, and the pebbles are somewhat less rounded than those of the Lower Terrace material. Yet the roundnesses appear to be related and the sediments may have been deposited under similar conditions (Tricart, personal communication). The roundness curves indicate the same conditions

*) We only take into consideration pebbles with a maximal diameter > 4 cm for the following reason. The Triassic conglomerate is much finer and more compact than the Carboniferous conglomerates, and quartzite pebbles also occur in Triassic conglomerate. This conglomerate regularly enters into the river as pebbles consisting of Triassic conglomerate, but by later weathering it may be decomposed and thus the pebbles from within the conglomerate are set free. So quartzite pebbles with a certain degree of roundness may be found on the terraces, but their roundness is not a result of the influence of the river which deposited them here. As this kind of pebbles generally does not exceed 4 cm in diameter, we let the pebbles smaller than 4 cm diameter out of consideration in our analyses. In the Rubagón and Camesa regions we shall find this to be of much greater importance than it is in the Pisuerga region.

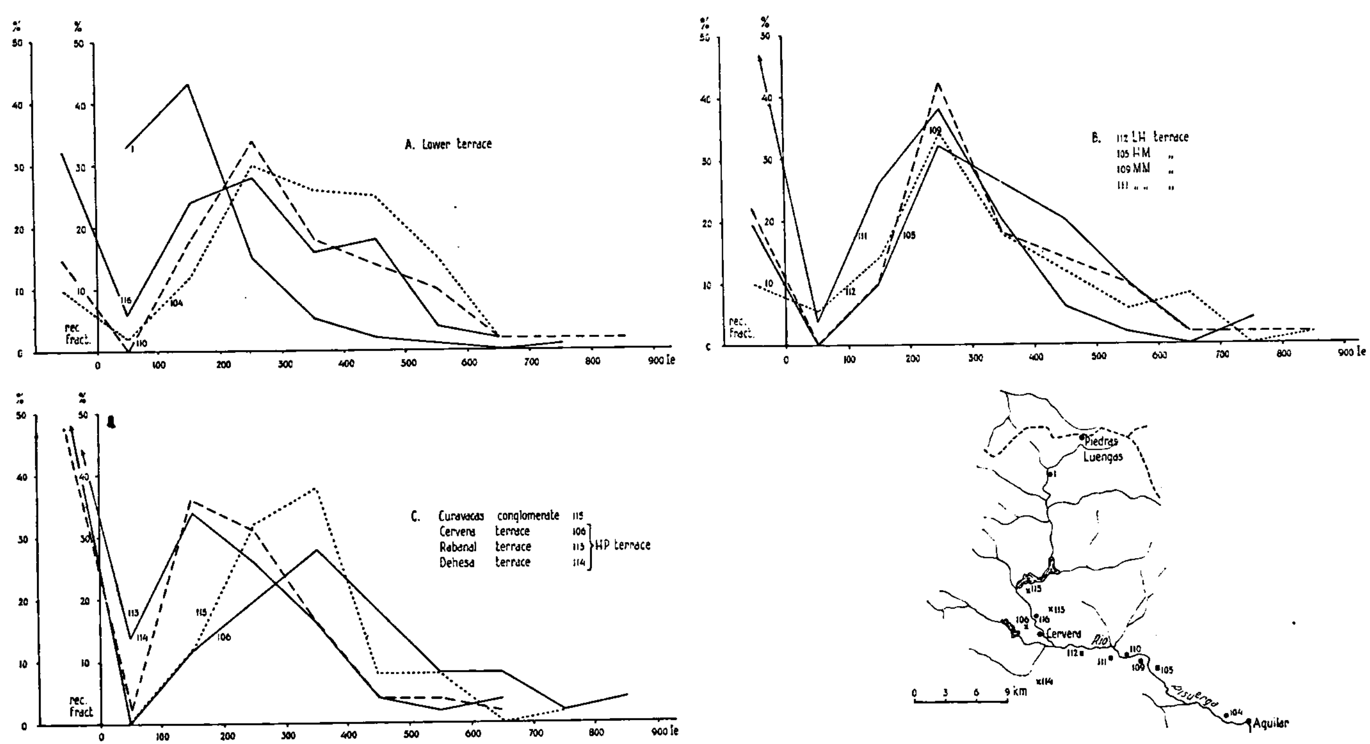


Fig. 21. Quartzite pebble roundness of the Pisuerga terraces.

as those of the Lower Terrace, but to a greater extent. Resumption of rounding after a fragmentation is clearly demonstrated by the high peak in the 200—300 index interval. These conditions can also be realised under a dry and warm climate but that appears to be excluded in this case, as neither the sand fractions (rounding by wind wearing) nor the surface of the pebbles (ferruginous coatings) give any indication of such a climate.

Thus the pebble roundness of both the Lower and the Middle Terraces point to deposition under periglacial climatic conditions.

The *HP terrace* is represented in fig. 21 C. A reasonably good rounding of the pebbles is evident; the Dehesa terrace part (114) is somewhat less rounded than the Cervera terrace part (106).

Tricart's remarks on these samples may be summarized as follows. The roundness graphs do not give any single indication of a cold climate. When comparing them to the Curavacas conglomerate, a rehandling without fragmentation is easily seen from the similarity of the curves in the 0—400 interval. This could not have taken place under a cold climate, so that we have to think of a temperate or warm temperate climate. It is also remarkable that the HP sediments are even considerably better rounded than the original Curavacas conglomerae. Partly this may have been caused by differences in roundness degrees of the pebbles from different beds of the Curavacas conglomerate, but even if this were so (which has not been investigated), a suitable explanation remains difficult.

Contrary to the Middle and Lower Terraces, the HP terrace appears to have been deposited under a temperate climate. The huge masses of gravel sediment (still 12—15 m in thickness) combined with the large area over which it was spread out (even now surfaces of many square kilometres are preserved) point strongly to a deposition by heavily over-charged rivers with (as can be observed) a rather low gradient. One may imagine the fluviatile system as consisting of rivers coming down from the mountains with steep gradients in rather narrow valleys, spreading out over an intramontane plain (cf. Chapter XI). The rapid decrease of gradient and the considerable bed load caused the formation of braiding rivers which had to deposit their overcharge of sediment. This of course consisted mainly of the coarsest pebbles. The facts described above imply that large quantities of debris were available, and that the type of weathering must have been so as to loosen easily the matrix of the Curavacas conglomerate.

Grain size of sand and clay

In the two preceding paragraphs we discussed the terraces in the order from low to high, because in this way the influence of the Curavacas conglomerate could best be demonstrated. In the following paragraphs there is no reason to take the lower terraces into consideration first, so from now on we shall follow the natural sequence, starting with the higher terraces.

The HP terrace. — The grain sizes of a number of HP samples are represented in fig. 22, in which the log cumulative curves have been united into a zone. All samples analyzed, except for one, fall within this zone. The histogram represents a sample which is most in accordance with the "average curve" of the zone. Some statistical values are presented in table 3. As we saw, the Herreruela- and San Felices terrace parts do not bear a sedimentary cover like the Cervera and other parts. Yet the size frequency curves of

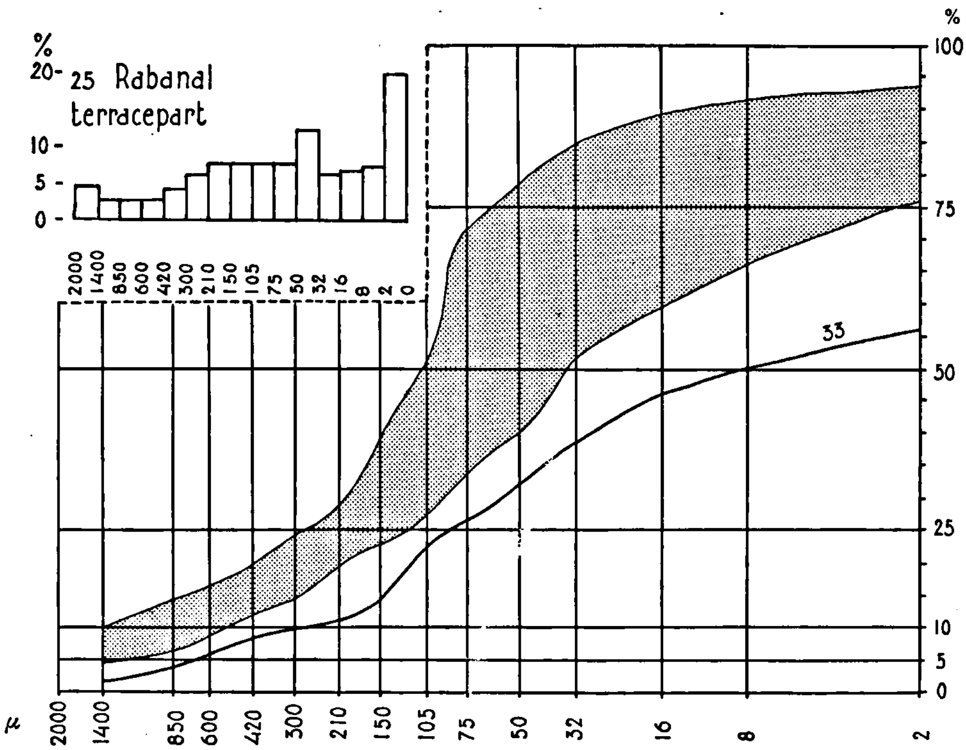


Fig. 22. Log cumulative graph of grain size distribution of the HP sediments < 2000 μ; curves united into a zone. Horizontal axis: grain size in μ. vertical axis: percentage.

samples from the surface of these terrace parts appear to fall within the zone. Perhaps a residue of a sediment is present, but it seems more probable to us that the weathering product of the terrace surface happens to have the same grain size frequency as the sediments elsewhere. The sorting degree was computed after the Trask formula $So = \sqrt{\frac{Q_1}{Q_3}}$. The sorting increases in the downstream direction from the Cervera and Rabanal terrace parts to

TABLE 3.

Statistical values of HP terrace curves.

No.	Terracepart	Q_1	Md	Q_3	So	Sk
64	Herreruela	278	82	22	3.5	0.9
65	San Feliçes	128	28	5.2	5	0.8
25	Rabanal	174	52	7.4	4.8	0.5
33	Cervera	78	7.4	—	—	—
73	Cervera *)	—	220	2.8	—	—
40	Dehesa	240	118	60	2	1.7
60	Dehesa	156	76	23	2.6	0.6
71	Dehesa	280	105	36	2.8	0.9

*) not in zone.

the Dehesa terrace part, which is quite normal, but remains low. The Herreruela-San Felices region is different; the bad sorting of the San Felices material does not point to fluviatile transport, and this may be an argument in favour of our point of view that the surface material of these terrace parts is not the residue of a former sediment, but a weathering product of the underlying Carboniferous.

Generally the terrace sediment contains some clay which is in most cases less than 25 %. As an exception a top in the coarse sand fraction is found

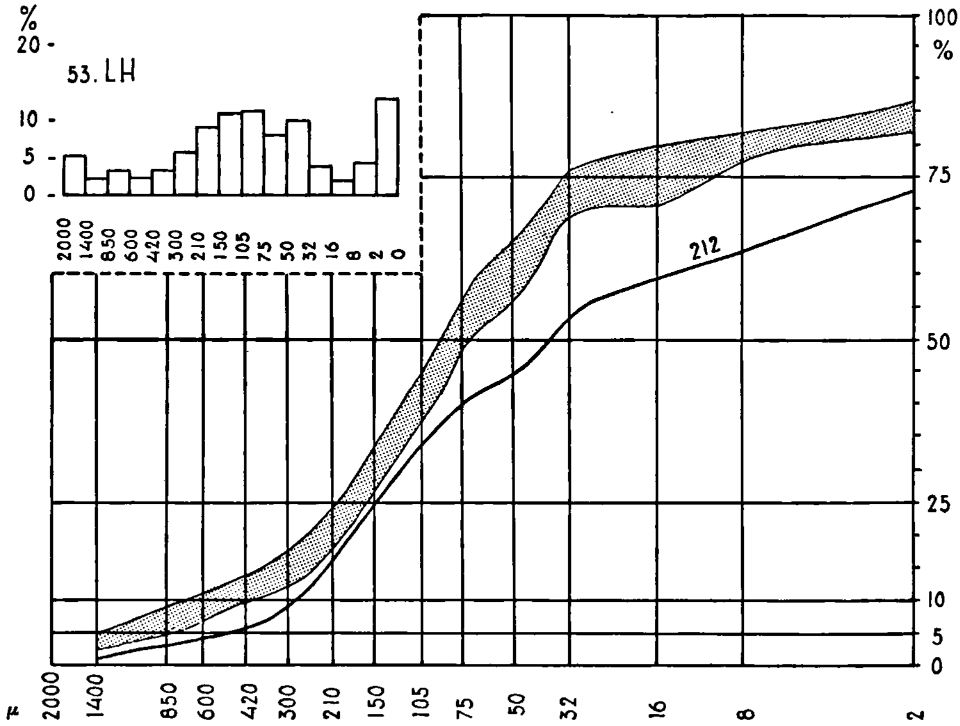


Fig. 23. Grain size distribution of the sediments at the surface of the LH terrace.

in one sample, but as a rule, none of the fractions contains more than 12 % of the total weight, which illustrates once more the bad sorting. In most samples the silt content is rather high with respect to the other non-clay fractions. This may point to some eolian action, which is confirmed by the shape of the quartz grains, to be discussed in a following paragraph. The sediment, thus, appears to be deposited under important variations in stream velocity (as indicates its bad sorting), whereas on the flood plain some local wind action took place, be it that it was of only subordinate importance (as indicates the silt content).

The LH terrace. — The LH terrace part of Cervera is considered as an erosion level which was formed in the HP terrace surface. Its surface is free of pebbles. In Chapter V we described the occurrence of a reddish layer below the HP terrace cover. At the surface of this LH terrace part the same material is found. The distance between the outcrop below the HP

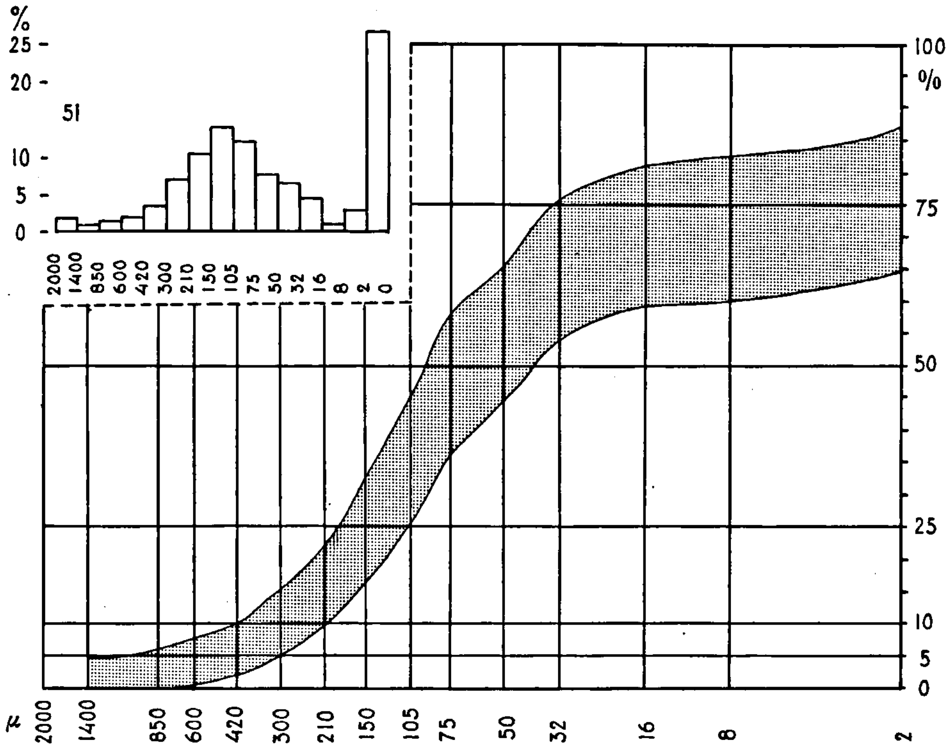


Fig. 24. Grain size distribution of the reddish layer below the HP terrace cover and on the LH terrace.

TABLE 4.

Statistical values of LH and red layer curves

No.	From	Q_1	Md	Q_3	So	Sk
31	LH surface (Cervera) ...	158	77	16.3	3.4	0.4
32	idem	164	69	10.5	3.9	0.4
53	LH surface (Arbejal) ...	196	90	35	2.7	0.9
47	Boring 1; 30 cm	165	85	35	2.2	0.8
49	„ 60 cm	150	84	23	2.6	0.5
50	„ 80 cm	185	90	8	4.8	0.2
51	„ 95 cm	155	80	—	—	—
52	Boring 2; 90 cm	115	40	—	—	—
58	Below HP gravel	105	41	—	—	—
212	Humín	155	38	—	—	—

sediment and the LH surface is small enough to conclude from the similarity of grain size distributions — as will be shown in this paragraph — that we are dealing with one and the same layer. On the LH terrace surface some handborings could be carried out thanks to the absence of gravel. These borings demonstrated the presence of the same material to a depth of at least 1.20 metres below surface.

In fig. 23, the curve zone represents the grain size frequencies of samples from the LH terrace surface at Cervera. A complex top is present in the

75—150 μ interval; the material consists of silty or clayey sand. In fig. 24 log-cumulative graphs are represented of the just mentioned reddish material (four samples from one borehole, one from another boring and one from below the HP terrace cover). Downwards the clay content slowly increases, probably as a result of illuviation. Further, all samples show a clearly developed top in the 75—300 μ interval. From these curves, and also from the colour and the structure of the sediment, the conclusion can be drawn that the reddish layer from below the HP terrace cover continues at the surface of the LH terrace parts, which confirms our opinion that the LH terrace is an erosion step, cut into the HP terrace surface. In Chapter V we mentioned already that this layer should not be considered as a fossil weathering soil of the underlying shales, but as a fluviatile sediment, as it is too homogeneous in a vertical sense. Moreover, the grain size distribution is clearly bi-phasic (Bakker & Müller, 1957; Mohr & Van Baren, 1954). This bi-phasic character of the sediment seems to point to a deposition by a river with large seasonal variations in stream capacity and velocity; moreover it may point to some vegetation on the flood plain (Bakker, personal communication). The reddish colour of the sediment may point to a rather warm climate. Some soil profile development in this sediment may be concluded from the downward increase of clay content; before the deposition of the HP terrace gravel it must have been truncated.

This reddish layer at the surface of the LH terrace, thus, is not of LH age, but much older, namely a sediment from pre-HP times, and possibly deposited by the initial rivers of the system which later on was to deposit the HP terrace gravel.

For the absence of gravel on this part of the LH terrace no satisfactory explanation can be given. It might be possible that in the LH time less pebbles were available, because of a less intensive weathering of the Curavacas conglomerate. Also deposition of the pebbles upstream of the region discussed might have been a factor, though this seems rather improbable to us. If ever gravel of LH age has been deposited on this terrace part, it has been removed by erosion afterwards. The only thing we are sure of, is that no pebbles are present at the existing surface of this LH terrace part.

From Cervera the LH terrace bends to the east, and is found again as a remnant at Ligüerzana and in the Barrio and Humín terrace parts. These terrace parts are strewn with pebbles but less abundantly than is the case on the other terraces, as was described in Chapter V. The particles $< 2000\,\mu$ of the Humín terrace part were also submitted to granulometric examination. This material appears not to be related to that of the reddish layer discussed above because of clear differences in granulometric composition. This Humín sediment is the real sediment of LH age. The sorting is worse, which is also a confirmation of the difference between both sediments (cf. curve 212 in fig. 23).

In table 4 some characteristics of the samples are summarized.

The Middle Terraces. — Some representative samples are plotted in fig. 25, where one of them is also represented in a histogram. Two, and most probably three levels can be distinguished in the Middle Terraces as was pointed out in Chapter V. Curve 211 represents the HM terrace, whereas the MM and LM levels have been united into a zone. The sorting of all sediments is bad, as is demonstrated, besides the graphs, by table 5. The bad sorting of each group points to great variations in stream velocity during

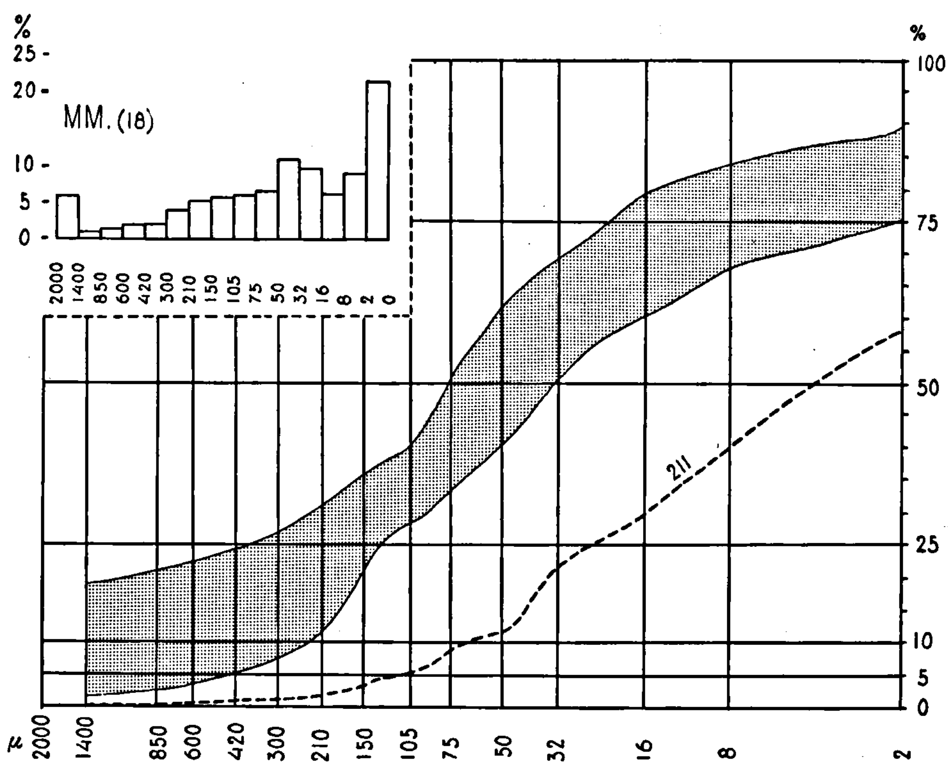


Fig. 25. Zone diagram of grain size distributions of Middle Terrace sediments < 2000 μ

TABLE 5.

Statistical values of the Middle Terrace curves.

No.	Terrace	Q_1	Md	Q_3	So	Sk
211	HM, San Mames	27	3.9	—	—	—
6	MM } Barcenilla	420	73	18.5	4.8	1.5
7	„	210	54	12.5	4.1	0.9
8	„	145	35	3	6.9	0.3
3	LM	300	83	21.5	3.8	0.9
29	„	265	59	11	4.9	0.8
30	„	136	48	2	8.2	0.1

the deposition of the sediment on all of the three levels; we are inclined to assume sedimentation under braiding river conditions. In times of less abundant debris supply, the river may have accomplished some downcutting. This may have repeated itself three times. Locally some eolian re-working of the sediment as it lay exposed on the flood plain, may be deduced from the silt content of most of the samples.

The Lower Terrace. — This terrace is situated 0—5 metres over the present bed of the river. Locally, sediment is found at 5—10 m. In that case we speak of a HL terrace level; it only occurs east of Aguilar.

In fig. 26 curve 201 corresponds to this HL level at Aguilar; all the other curves represent the Lower Terrace. The curves do not show the slightest relation to each other and no increase of clay content or of sorting degree in the downstream direction can be observed. Some subordinate eolian action seems to be reflected in the samples 46, 104 and 202. In table 6 some statistical data are given; the samples are ordered in the downstream direction.

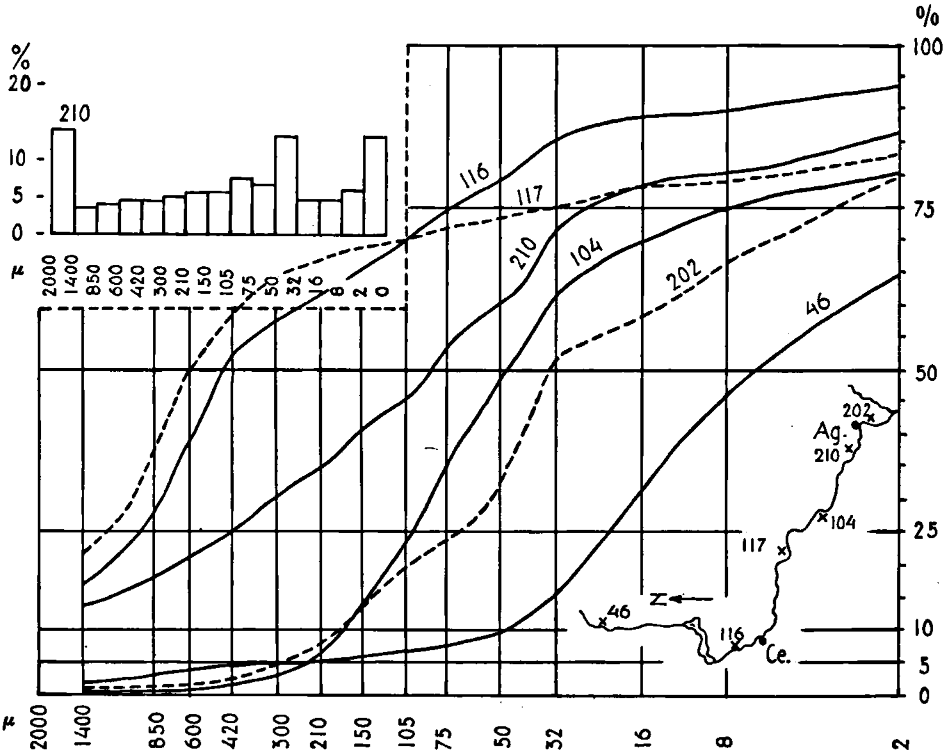


Fig. 26. Grain size distribution of the Lower Terrace sediment. < 2000 μ

TABLE 6.

Statistical values of the Lower Terrace curves.

No.	From	Q_1	Md	Q_3	So	Sk
201						
46		20	6	—	—	—
116		1250	600	32	6.2	1.1
117		900	450	75	3.5	0.3
104		105	46	8	3.6	0.4
210		470	85	22	4.6	1.4
202		84	32	3.9	4.6	0.03

Roundness of quartz grains in the 500—1050 μ interval

The roundness of quartz grains was determined in the way described in Chapter I; the preparatory treatment had to be carried out with diluted, sometimes even concentrated HCl and HNO_3. The results are plotted in frequency curves; these are arranged according to the relative heights of the terrace groups. Together with the tables they give a convenient impression of the roundness and shape of quartz grains.

The HP terrace (fig. 27 C; table 7). — Indices between 0 and 200 are largely dominant, the other index groups being of very subordinate significance. All the curves fall within a narrow zone of the diagram. The highest index grains mostly have a worn appearance, and appear to be not bound to any diameter. The simple shape of the roundness curves points to a short uncomplicated transport of the material; the amount of grains "frosted rounded" may point to eolian action, as was also noted from the grain size analyses. Most probably the sediment has been blown to some extent when lying exposed on the flood plain after its deposition by the river. Apparently

TABLE 7.

Mean roundness and shape of quartz grains, HP terrace.

No.	Terracepart	mean Ie	Not rounded		Rounded	
			not frosted	frosted	not frosted	frosted
64	Herreruela	91	77	7	—	16
65	San Felices	94	94	1	—	5
33	Cervera	90	76	10	—	14
73	Cervera	96	91	—	7	2
25	Rabanal	129	77	7	—	16
40	Dehesa	119	67	20	1	12
71	Dehesa	103	94	3	1	2

the eolian transport has been of subordinate importance only. Furthermore, at least a part of the etching might be ascribed to chemical attack, which would in particular be valid for the relatively large number of grains "frosted, not rounded". On this subject too little is known, however, to draw certain conclusions. In the tables concerning the shape of the quartz grains, we have not distinguished between "not worn", "water worn" and "wind worn" grains (as did Cailleux, 1952) but between grains being "not rounded, not frosted"; "not rounded, frosted", "rounded, not frosted" and "rounded, frosted", in order to leave open the possibility that part of the etching might have been caused by chemical attack.

LH level and the Middle Terraces. — In fig. 27 B frequency curves of the roundness of the LH and the Middle Terrace samples are represented. We have also included curves 32 and 212 (Humín) in this graph. The latter represents the LH terrace sediment, the former was taken from the LH level at Cervera. Curve 32 falls within the zone of fig. 27 C (HP terraces), curve 212 is much steeper, which points to a lower roundness degree. If the material were the same or narrowly related through deposition by the same river at the same time, a downstream increase in roundness might be expected, but the reverse is observed. Our point of view that the material lying on the Cervera-LH terrace part does not belong to this terrace at all, but that it is a sediment of an older age than the HP terrace, is once more confirmed by the differences in roundness found here.

Among the other curves, 211 corresponds to the HM level (San Mames), 7 to the MM level (Barcenilla) and 4 to the LM level (Vado). The HM material is very badly rounded, and so is the LM sample; the MM level

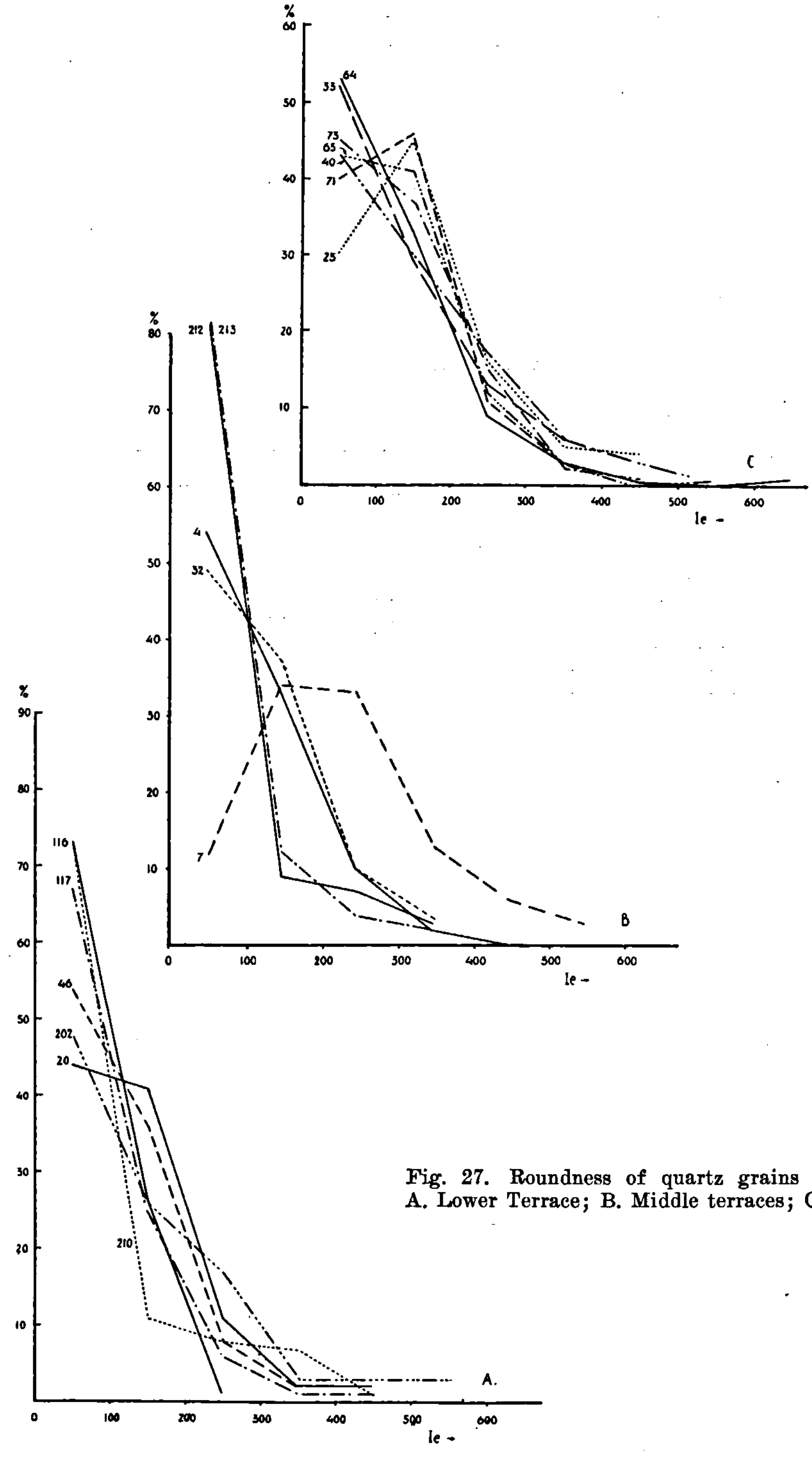


Fig. 27. Roundness of quartz grains 500—1050 μ; A. Lower Terrace; B. Middle terraces; C. HP terrace.

demonstrates a markedly better rounding. Considering the situation of this terrace part near Barcenilla, it becomes clear that the MM level may easily have been supplied with Wealden material, which is partly well-rounded already (cf. Chapter III). In the same way the LM terrace part at Vado may locally have been supplied with Devonian quartzite from nearby, and the HM terrace at the Humín with angular sand from Triassic sandstone. Moreover, no regional increase of roundness has been found in the MM terrace, so that we are inclined to explain those differences by local influences as described above. It is worthy of note that, except for sample 7, the grains are even less rounded than those of the HP terraces, and that the amount of grains rounded-frosted is considerably lower. Wind action, thus, appears to have played only a quite insignificant part.

TABLE 8.

Mean roundness and shape of quartz grains, LH and Middle terraces.

No.	Terracepart	mean Ie	Not rounded		Rounded	
			not frosted	frosted	not frosted	frosted
32	LH, Cervera	87	80	11	1	8
212	LH, Humín	39	100	—	—	—
211	HM, San Mames	33	99	1	—	—
7	MM, Barcenilla	207	88	1	4	7
4	LM, Vado	82	93	1	1	5

From what has been said above, it will be clear that the differences between the levels of the Middle Terraces can easily be explained from local influences, so that we need not assume climatic causes, though minor differences in climate are not excluded.

The Lower Terrace. — The curves of the Lower Terrace sands have higher peaks in the 0—100 index interval than those of the HP terrace. After what has been said about the HP and Middle Terraces, fig. 27 A and table 9 will speak for themselves.

TABLE 9.

Mean roundness and shape of quartz grains, Lower Terrace.

No.	From	mean Ie	Not rounded		Rounded	
			not frosted	frosted	not frosted	frosted
20	Redondo	100	80	14	—	6
46	R. Areños	74	92	2	2	4
116	Arbejal	37	97	3	—	—
117	Salinas	57	90	5	—	5
210	Dam Aguilar	61	97	1	—	2
202	S of Aguilar	111	98	2	—	—

Heavy mineral composition

Analyses and preparatory work on the samples were carried out in the usual way, while some additional observations were made on the shapes of the grains and their preferred position after the strewing on the slides. These observations are summarized here for the most important minerals of our region.

Tourmaline. Alteration products at the edges are always absent. Three main types of orientation of the grains occur:

a. Basal. Determined by { 0001} parting. Pleochroism apparently weak or absent, dark with crossed nicols. Can be confused with opaque minerals or basaltine.

b. Prismatic. Bound by the prismatic crystal planes. Maximum pleochroism visible.

c. Intermediate. Strong characteristic pleochroism always visible.

Zircon. Grains are idiomorphic in majority. Often more or less rounded at the top ends. Small influence of {110} cleavage.

Rutile. Mostly in rounded grains. Striping caused by {111} cleavage.

Anatase. Grains forms largely determined by octahedron planes {111} and by basal cleavage {001}. Mostly dark blue pleochroitic. White and yellow grains also were observed.

Corundum. Grains mostly lying on {0001}.

Brookite. Mostly situated on { 100 }. Always easy recognizable by its well-known optical properties.

Kyanite. Grain forms determined by the three cleavage directions {001}, {010} and {001}.

Staurolite. Grains often strongly attacked by weathering and alteration. No preferred orientation in slides, grain forms determined at random.

Topaz. Perfect basal cleavage according to { 001 } largely determine the grain forms.

Alterite. With the name alterite have been indicated these mineral grains of which can be said with certainty that they were once a nonopaque mineral, now weathered to such an extent that determination of the original mineral is absolutely impossible. In this group are also included those minerals which might be considered as saussurite.

In table 10 (in flap at the back of this paper) and in fig. 28 the heavy mineral composition of the Pisuerga terraces is represented.

Tourmaline, zircon and rutile are largely dominant over the other minerals. In the graphs representing the averaged compositions (fig. 28), either tourmaline or zircon is dominating; when comparing this graph to table 10 the reader will see that in the individual countings the differences are even more conspicuous. Though no fractionized analyses were carried out, we easily found that these differences are not, or at least not only, caused by "granulometric variations", which occur as a consequence of the fact that the zircon grains generally have much smaller dimensions than the tourmaline grains. Hence, the zircon is dominant in the finer-grained fractions, whereas tourmaline accumulates in the coarser fractions. When comparing the heavy mineral assemblages with the grain size analyses, we found that the finer grained samples are not always characterized by a high zircon content, and that the coarser samples do not always contain a majority of tourmaline. Thus, though granulometric variations of course will occur, as might appear from fractionized analyses, their effect is mostly obscured in our samples by the dominating primary differences.

In the *HP terrace,* the Castillería branch has a high tourmaline content and some staurolite (obviously supplied by the Triassic, cf. Chapter III); the western branch has a high zircon content.

Some of the conglomerate pebbles from the Dehesa terrace part were analyzed and were found to have a high tourmaline percentage and considerable staurolite and garnet contents. The high staurolite content (over 10 %

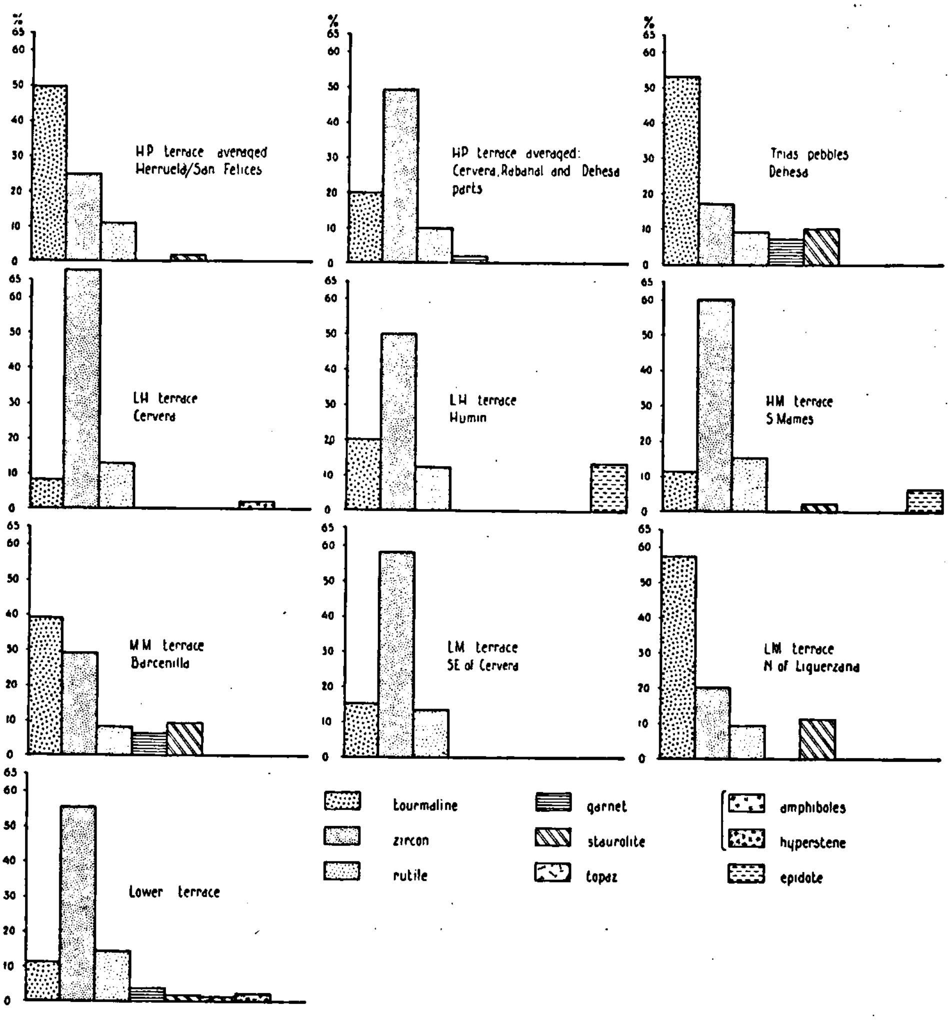


Fig. 28. Averaged heavy mineral compositions of Pisuerga terrace sediments.

as an average) is a definite indication that the pebbles consist of Triassic conglomerate.

The *LH level* both at Cervera and in the Humín region has a high zircon content, which may be explained in this case by the fine grained texture of both of the sediments, though they are not the same, as we saw before.

Of the *Middle terraces,* the HM level also has a high zircon content, and moreover 6 % of epidote and some 2 % of staurolite. The MM level, on the contrary, contains more tourmaline than zircon, and in general is richer in minerals (staurolite, garnet) which is perhaps due to a supply from the Wealden. The LM terrace, at Vado and east of Cervera, is rich in zircon; tourmaline, and rutile are the only other minerals present.

The *Lower Terrace,* finally, in all samples shows a striking low tourmaline content, and is found to be extremely rich in zircon. Other minerals, apart from rutile, occur in small percentages. The hypersthene is only present in some 10 % in the terrace outcrop near the intrusive rock at Arbejal (cf. Chapter III, fig. 7). When averaging in the diagram, it appears at some 1—2 %.

Dating and conclusions

In the *HP terrace time* the Pisuerga system was fed by two branches, one from the East, that is from the Triassic escarpment, and one, which was the most important, from the NW, that is from the region consisting of Curavacas conglomerate. Both branches joined near Polentinos. From the thickness of the sediment, the broadness of the terrace belt, and from the sedimentary petrography, we can conclude that the material was deposited by a system of braiding rivers. These rivers flowed through a zone of intramontane plains. In the mountains the rivers may have had a considerably greater gradient; when entering into the plains this gradient suddenly decreased and caused the heavily charged river to deposit its over-charge of sediment. The river flowed southward, along Cervera, and continued its southerly direction through the Brezo gate and over the present Dehesa terrace part. The continuation of the terrace farther southward is also important to us; it lies at a lower level than the so called "Paramo of Guardo". This is a high plain covered with angular, mainly quartzitic debris, which show the characteristics of sheetflood deposits. It therefore is an equivalent of the so called "rañas" elsewhere in Spain. It was mentioned by Birot & Solé Sabaris (1954b) and was investigated by Mabesoone (1959). The age of this raña is Villafranchian, probably Lower Villafranchian. The sheetflood deposits indicate the existence of a semi arid or even arid climate and such climates certainly have occurred in the Villafranchian (Woldstedt, 1958).

The HP gravel is found to continue as far as this raña, and then to bend to a southeasterly course, to Herrera. As the gravel lies at a markedly lower level than the raña surface, we may conclude that the HP sediment is younger than the raña. Its sedimentation is found to have taken place under a temperate and probably rather humid climate, so we may conclude to an important climatic change since the deposition of the raña sediments.

The analyses of the terrace sediment exclude glacial or periglacial influence on the sediment and hence also a glacial or periglacial climate. On the other hand, the terrace sediment will have needed considerable time to have been deposited in such a thick layer (12 metres) over such a broad zone.

Two glaciations have been recognized in Spain, and generally they have been parallelized with Riss and Würm (Obermaier, 1921; Nussbaum & Gygax, 1951—52; a. o.); one author thought to have recognized three glaciations (F. Hernandez Pacheco, 1944), the oldest of which he correlated with Mindel. Though there may be objections against his arguments, it seems certain that, if not a glacial, at least a periglacial climate in the higher mountains may be presumed for the time that can be parallelized with the Mindel glaciation elsewhere in Europe. Such a climate certainly would have influenced the sediments, mainly the pebbles, dating from that time. The same could be argued for the climate of the "Günz" time, though, of course, in this case the arguments are somewhat less convincing. Perhaps at that time the climate was of a pluvial type. As we saw that indications for a glacial or periglacial reworking of the pebbles from the HP terrace are absent, we can state now that its age must be certainly older than Mindel and younger than Old or Middle Villafranchian. Furthermore, a rather long period with about the same temperate humid climate is required for its deposition. Most probably, thus, the HP terrace sediment is of Young Villafranchian age.

As we saw, before the sedimentation of the HP terrace gravel a fluviatile sediment with a bi-phasic grain size frequency was deposited. This sediment must be younger than the planation surface it lies on, and as will be seen in Chapter XI this planation surface certainly is not older than the raña time. The rañas are looked upon as a deposit of a semi arid climate (Oehme, 1936; Solé Sabaris, 1952; Woldstedt, 1958) whereas the HP sediment was deposited under temperate and most probably rather humid conditions. Between the raña time and the time of the highest terrace, a warm and humid climate is presumed by Mabesoone (1959) from whom we cite:

> "After the deposition of the rañas the climate changed again, becoming more humid. In this time the well-known Villafranchian fauna, according to De Villalta (1952) could have lived. Also an argument in favour of such a climate is the strong desintegration of the quartzite pebbles, at present found on the raña of Guardo. Such desintegration only can develop in a warm and humid environment."

In Villaroya, southeast of Logroño at a distance of about 250 km from Cervera, a beautifully developed Villafranchian profile is found in which various important climatic changes in the Villafranchian could be established. Thus, it seems very well possible that the bi-phase sediment from below the MP terrace sediment corresponds to the warm and humid climate mentioned above. The colour of the sediment is reddish or brown-reddish, which is in accordance with such a climate.

Not very long after the HP sedimentation, the "High Pisuerga" must have been captured by a river flowing to the E or SE, which had a strong headward erosion as it flowed in a subsequent course through soft Mesozoic deposits north of the limestone ridge east of the Brezo gate. We cannot make sure at what place the divide was situated before the capture, and certainly the process will have had various stages. As a result of the capture, the Pisuerga was diverted from Cervera to the East. The new valley floor is now found as the LH terrace. It is developed as an erosion step in the HP terrace surface upstream of Cervera, and in this part it is free of pebbles. The other remnants, at Ligüerzana and the Barrio-Humín parts, are covered with pebbles which are markedly scarcer strewn than on the other terraces.

Upstream of Arbejal no traces of an LH terrace are found, neither downstream of the Humín terrace part. Southeast of the Humín the river probably has been blocked in its course by a resistant limestone ridge, through which it passed in a gorge which now has widened to a "cluse". The blocking effect was the cause of considerable lateral erosion upstream of the ridge, where now the Barrio and Humín terrace parts are found. Downstream of that ridge the river may have steepened its gradient, as will be clear after the discussion of the Rubagon and Camesa terraces. Possible remnants of the counterpart of the LH terrace have disappeared completely by younger erosion.

Upstream of Cervera no traces of Middle Terraces were recorded, except perhaps at San Salvador. At present considerable lateral erosion takes place in the Pisuerga course upstream of Cervera, and from the extension of the Lower Terrace we see that this lateral erosion has even been much stronger in the Lower Terrace time. Remnants of Middle Terraces thus may easily have been destroyed by younger erosion, and by now nothing has been left of them. On the other hand there is the possibility that in the Middle Terrace time the longitudinal profile of the Pisuerga was of a different shape so that no valley floor existed upstream of Cervera, and that for this reason no remnants of terraces are found. We cannot make sure which of the two cases has occurred.

Of the MM terrace, the Barcenilla part has a rather peculiar situation, which is illustrated in fig. 18, and which was discussed in Chapter V. The Pisuerga never passed through the broad valley of the Barrio's. East of Salinas extends a zone of very soft Jurassic marls. The Pisuerga, instead of following this zone of soft layers, bends to the southeast after Salinas and cuts its bed through a resistant limestone belt. This illustrates the superimposed character of the river; the successive courses during the different terrace times are illustratd in fig. 18 (Chapter V). Downstream of Villanueva de Pisuerga it passes through the "cluse", mentioned previously in this paragraph. The northern slope of the ridge in which the cluse had formed, is a dip-slope plunging towards a depression which is hardly higher than the level of the Pisuerga; this is the point where the road passes. But on this low point the Pisuerga has never passed, as gravel or any other kind of fluviatile sediment is completely absent.

As to the Lower Terrace we mentioned already the situation downstream of Aguilar, where the confluence of the Pisuerga and Camesa shifted to the South over a distance of several kilometres, since HL times. Dating the Middle and Lower Terraces is difficult, because no archaeological, palynological or other palaeontological data are available. First we shall make an attempt to date the Lower Terrace. Along the whole course of the river we see it has cut down at least 2 metres into the Lower Terrace, and at various places it cut entirely through it. As this incision occurs along the whole length of the Pisuerga, we may attribute it to a non-local influence, which in this case must be the climate. This incision is recorded along the whole course on the Meseta, gradually increasing so as to bring the Lower Terrace, farther downstream, at a relative height of over 10 metres. From the sediment analyses and from the debouching of various "dellen" on the Lower Terrace surface, it seems justified to ascribe the Lower Terrace to the latest glacial period, which may be correlated with the Würm glaciation *).

Because of the similar physiographical and sedimentological features of the Middle and Lower Terraces, we may ascribe the Middle Terraces to cold periods, too. Because of the considerable relative height of the Middle Ter-

*) Most of the Spanish authors parallelize the glaciations found in Spain, with those of the Alps. Riss and Würm glaciations have been found at many places, the occurrence of older glaciations is uncertain as yet.

races, it is most probable that they are not from the latest cold period, but from an older one. Possibly they are of Riss age, and correspond to two or three stages of this glaciation, but the higher levels might correspond to older glacial phases as well. Though the occurrence of a Mindel glaciation in Spain is still a point of discussion, and the Günz glaciation has not been recorded at all, we may suppose that at the times corresponding to the Mindel and Günz glaciations elsewhere in Europe, periglacial conditions might have influenced the weathering phenomena in the Cantabrian Mountains, certainly in the Mindel time.

In a review of the terraces of the five principal rivers of Spain, E. Hernandez Pacheco (1928) parallelizes the 30 m-terrace of the rivers to the Riss glaciation and the 70 m-terrace to Mindel times.

Combining all these arguments it seems most probable that at least the LM and MM terraces are of Riss age; the HM level might be older, but the correlation of this level with the terraces downstream of Herrera is difficult; this subject would be worth a special study. We therefore prefer not to give a definite conclusion as to the age of the HM level before more data will be obtained for correlating it with the terraces downstream of Herrera (see also Mabesoone 1959).

From the absence of periglacial features, reflected in the sediment, we see the LH terrace is not of a glacial origin; as we saw before, it even is not of a climatic origin at all, but merely formed as a result of the capture of the High Pisuerga. It must be older than the HM terrace, so probably older than Mindel age — and at any rate older than Riss —, and younger than the HP terrace, to which a Young Villafranchian age can be attributed.

CHAPTER VII

DESCRIPTION OF THE RUBAGÓN TERRACES

The Rio Rubagón is largely different in character from the Rio Pisuerga. Its drainage area is much smaller; actually, it is a tributary of the Rio Camesa, into which it discharges at Quintanilla de las Torres. The Rubagón also is accompanied by a belt of terraces but these are of a quite different type. They are situated at lower relative heights, and the areas occupied by them are much smaller.

The Rubagón terraces can be divided into four groups, as will appear from the sediment analyses. For the sake of readability we shall describe the individual terrace parts in the order of the terrace group they belong to. The four levels, which are also readily recognized from their different relative heights, are:

HR terrace, relative height:	55—70 m
MR „ „ „	40—50 m
LMR „ „ „	15—20, locally 25 m
and Lower Terrace, „ „	0— 5 m.

In fig. 29 a longitudinal profile of the Rubagón is presented, with the projection of the terraces. The individual terrace parts are numbered in the downstream order; in the descriptions the individual terrace parts are indicated with the same numbers. The longitudinal profile of fig. 29 is plotted as far as the outlet point at Quintanilla de las Torres.

The HR (High Rubagón) terrace

On the eastern bank of the river, remnants of the HR terrace are found. Off Porquera de Santullán, that is about 2 km south of Barruelo, a ridge is present, east of the railway. This ridge has a more or less flat top, and on this top a gravel cover is found consisting of quartzitic and Triassic pebbles. Though they are badly rounded, indications of fluviatile transport are unmistakably present, thus proving the gravel to be a remnant of a terrace cover. Its height is 1055—1060 m, that is 55—60 m relative. The thickness of the gravel is difficult to determine because of its incomplete preservation; the present thickness may be about 2 m, but this gives no idea of the original thickness of the layer. We shall refer to the ridge as the *terrace remnant of Porquera de Santullán* (4) (fig. 30).

About 2½—3 km farther south on the same eastern bank a hill with a flat top is found just east of the railway station at a height of 1025—1030 m, which corresponds to a relative height of 65—70 m. Its flat-topped surface is covered with badly rounded blocks and pebbles, consisting of quartzites, Triassic rocks, and blue-black Carboniferous limestones. The slopes of the hill are also covered with pebbles, which, strange enough, seem to be better rounded. This terrace part will be called the *Station terrace part* (6) (fig. 30).

The thickness of the sedimentary cover differs from one side to the other and is on the average about 3 m, though locally a thickness of 6—7 m could be recorded. South of the road to Vallejo, it continues as the *Cillamayor terrace part* (7). This also has a relative height of about 70 m and a sedimentary cover of 5 m thickness at most, consisting of quartzitic and Triassic pebbles.

To the northeast of the Station terrace part and east of the other terrace

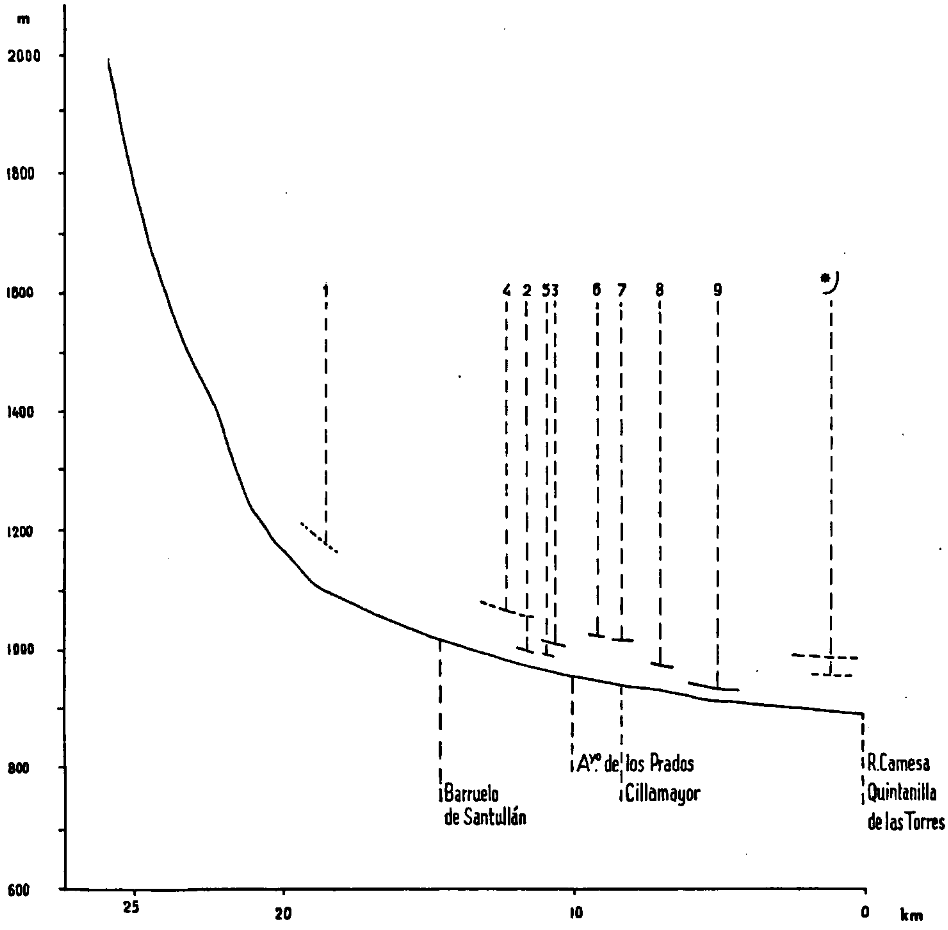


Fig. 29. Longitudinal profile of the Rubagón, with projection of terrace parts.

parts on this bank of the river, other, partly bush-covered hills extend towards the Triassic ridge of the Sierra de Brañosera. These hills are covered with angular blocks which are easily recognized as "slope-blocks" transported downslope by gravity, may be under a periglacial climate. The surface has an inclination of some 4°, rising up to the Triassic ridge. Locally outcrops occur of the same rock as that of which the blocks consist. This type of denudation slope rises up from the terrace area over a considerable distance until the slope angle abruptly changes to a steeper final slope of 18—24°, often with a more or less rectilinear profile, rising up to the culmination of the Triassic ridge (fig. 5 & 30). This is another example of the phenomenon, mentioned several times before, that the terrace parts or terrace areas are bordered by small-angle denudation slopes (cf. Chapter XI).

Farther downstream, west of the present Rubagón valley, three terrace parts are found which have a peculiar situation with respect to the river. Because of their situation in the Rubagón drainage area we shall give a description of them in this chapter, but later on we shall see that they are also related to the Camesa terraces. The three of them are situated at about the same level, and obviously they once were parts of one terrace plane. The remnants of this plane, formed by the three terrace parts, extend from Nestar to a region some 2 km north of Aguilar de Campóo, passing along the village of Matalbaniega.

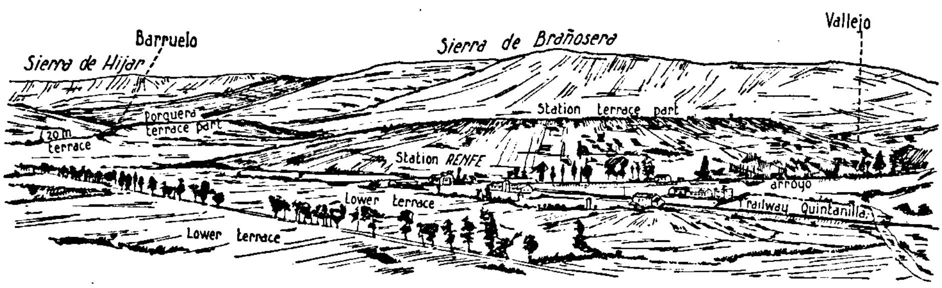


Fig. 30. Rubagón valley and terrace parts seen to the NE.

The northernmost part is situated northwest of Nestar at a height of 990—1000 m, that is 60—70 m relative to the Rio Rubagón. It consists of a flat-topped hill, covered with wood and bush, with a sedimentary cover of considerable thickness which could be measured at some places to be 10—12 m. The sediment is well preserved but the complete lack of any outcrop under the wood cover made it impossible to take samples or to carry out pebble analyses. On visual estimation the pebbles were found to consist of a mixture of Triassic conglomerates and sandstones, quartzites, and quartzitic sandstones. Often very large blocks, even exceeding 1 metre in diameter, were met with.

At *Matalbaniega* the second part is found. It has a height of 980—986 m, and consists of a hill with a flat, slightly rounded top. A relative height is better not given because apparently no relation with the present Rubagón exists. A sediment layer of 10 m thickness covers the hill, the sediment consisting of Triassic and quartzitic pebbles, mixed up with small quantities of locally outcropping Mesozoic limestone.

The southern part is a ridge extending along part of the road from Aguilar to Nestar at about 980 m. Over a length of more than 2½ km a gravel cover is present on it, with a thickness of about 8 m, gradually wedging out towards the southern end. The gravel association is the same as that of the two other parts: gravel up to large dimensions, consisting of Triassic and quartzitic pebbles.

As we remarked, these three terrace parts are to be considered as remnants of one and the same ancient level, which is easily recognized in the field. Several more or less flat-topped hills occur in the same area, without gravel deposits though in the valleys between them at a great many places gravel is present which undoubtedly has been carried down from the terrace surfaces, as is easily confirmed by their pebble associations.

The MR terrace

On the right bank of the Rubagón a remnant of the MR terrace level is found north of the village of Matabuena, and hence is called the *Matabuena terrace part* (3) (fig. 31). Its surface is slightly undulating as a result of gully erosion and dellen formation. The sedimentary cover is still about 3 metres in thickness, and overlies Palaeozoic and Mesozoic rocks. To the west and northwest this terrace part is bordered by a gradually rising denudation surface which is partly dissected but which can clearly be recognized (cf. fig. 50, Chapter XI). Similar phenomena were observed in the Pisuerga area

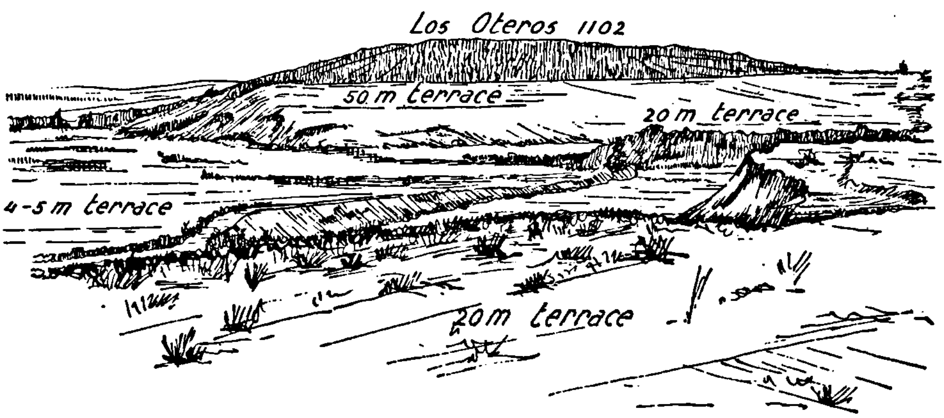


Fig. 31. Revilla (20 m) and Matabuena (50 m) terrace parts seen to the S.

(cf. Chapter V), so that it seems that they are of more than local importance.

The relative height of the Matabuena terrace part was found to be about 50 m. On the left, that is the eastern bank, north of the intersection point of the Renfe and "La Robla" railways, a terrace part is found at a relative height of 40 m, that is at an absolute height of 980 m (8). Its surface is covered with a layer of gravel probably 2—3 m thick. Because of the lack of outcrops, and because of solifluction through which the slopes became covered with the same gravel, an exact measurement of the gravel thickness was not possible. The pebbles consist of conglomerate and quartzitic sandstones. Rather rounded blocks, up to 1 m in diameter are found on the top surface. A "step" before the western front of the terrace part lies at a level of 5—10 m relative and is obviously narrowly related with the Lower Terrace.

At *Brañosera* (1) the most upstream terrace-like surface is found. It can not be stated with certainty if this is a real fluviatile terrace or not; it has a flatty surface at 1210 m, that is at a relative height of about 50 m. Some big angular Triassic blocks are found on its surface, but as all the surrounding ridges are built up of Triassic, this has no significance for determining whether it is a fluviatile terrace or not.

The LMR terrace

On the western Rubagón bank, the *Revilla terrace part* (2) (fig. 31) is found southwest of Revilla, at a relative height of 15—20 m. On the lower side it is bordered and undercut by the present R. Rubagón; on the high side it is bordered by a limestone cliff. The terrace sediment is 2—2½ m thick and overlies Carboniferous shales; it consists of coarse gravel mixed up with sand and clay. The terrace surface is flat and obviously well preserved.

Opposite, on the eastern bank of the Rio Rubagón, an LMR terrace part is found at about *a kilometre south of the Porquera terrace part*. It consists of a round-topped hill, covered with gravel, at a height of about 20 m relative. The thickness of the gravel cover could not be measured exactly in outcrops, the slopes of the hill being also covered with the same gravel as a result of solifluction and soil creep, but it can be estimated at 2—3 metres. In the longitudinal profile of the Rubagón (fig. 29) this terrace part is indicated with (5); it is also visible in fig. 30.

About 1 km NNW of Nestar, a rather extended terrace remnant is present at a relative height of 15—20 metres; it consists of a long low ridge with a convex top profile in which no flat surfaces can any more be distinguished. It is richly strewn with pebbles and hence we may presume that its original height has not much exceeded its present level. This terrace part is called the *Nestar terrace part* (9).

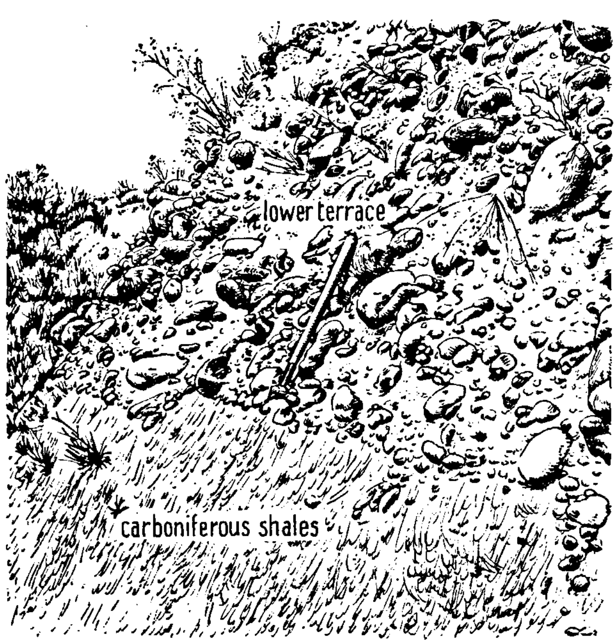


Fig. 32. Lower Terrace south of Porquera de Santullán.

The Lower Terrace

The Lower Terrace is present downstream from Revilla de Santullán along the whole course of the river. From its beginning it widens to a valley floor with a width of over 500 m, at 4—5 m over the river. The sedimentary cover was found to be 2—2½ m thick; the present river has cut through it and also through 2 or 3 m of the underlying Carboniferous rock (fig. 32). As might be expected the gravel consists again of quartzite and Triassic, detailed data being given in Chapter IX. The winter bed of the Rio Rubagón is much higher than the summer bed, to which we refer as field work was carried out in summertime, and as a marked boundary between winter bed and Lower Terrace is often absent. At some places braiding courses of the present river were found, which obviously are occupied only in winter season. This is easily established because of the presence of coal waste from the mine washing at Barruelo. At Cillamayor the Lower Terrace widens at the outlet of a broad valley from the W. As at present no water runs off through this valley, we consider it as a delle (dry valley, cf. Schmitthenner, 1926) of the flat-floor type. Its debouching at the surface of the Lower Terrace is once more an indication of an equal age, viz. Würm glacial, of both of them (cf. Chapter VIII). From here the Lower Terrace continues with varying but always considerable width; the thickness of the terrace cover slowly increases to the South, but we may safely say that nowhere it exceeds 3—4 m. Its relative height always remains between 1 and 5 m. Where the river passes through the Camesa terraces at Quintanilla (to be discussed in Chapter IX) its Lower Terrace narrows considerably and so it remains until its outlet into the Rio Camesa.

Along the course several traces of ancient meanders and cut-off meander cores were found; these do not need extensive discussion, and can be regarded as indications of the meandering type of river prevailing during some period of the Lower Terrace time.

It is noteworthy that the R. Rubagón is subject to a considerable loss of water, mainly in the part downstream of Cillamayor, which may be attributed to the presence of Mesozoic limestones in the subsoil.

CHAPTER VIII

SEDIMENTARY PETROGRAPHY OF THE RUBAGÓN TERRACES

Pebble associations

Regarding fig. 33, in which some of the most characteristic gravel associations are represented in simplified graphs, the reader will readily observe a tendency to a decrease of the quartzite content with decreasing relative height of the terraces. The content of Triassic material remains constant at 20 to 30 %, with few exceptions.

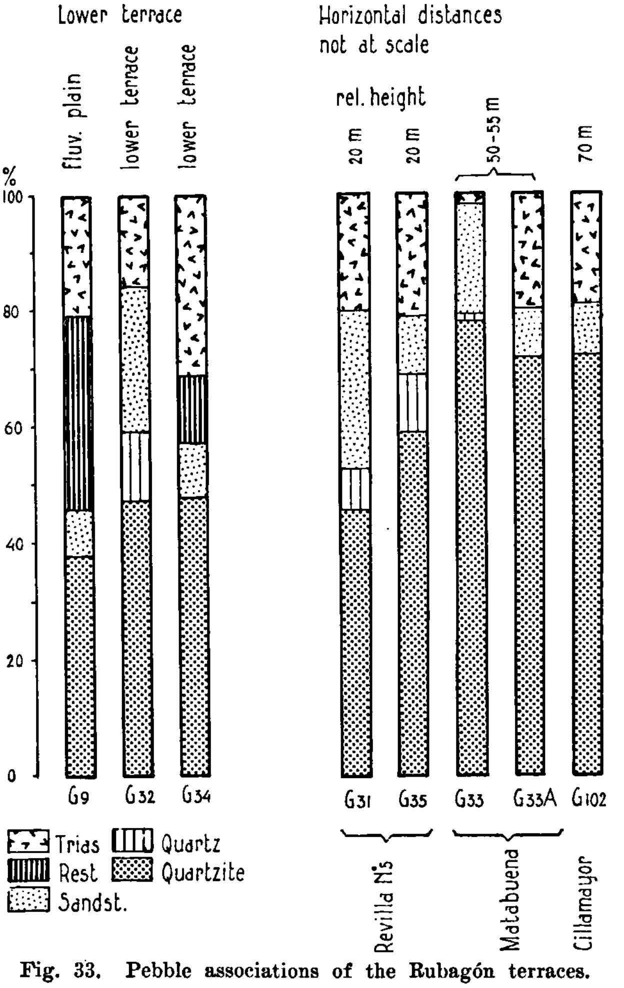


Fig. 33. Pebble associations of the Rubagón terraces.

The presence of quartz must be attributed to decomposition of the Triassic conglomerates; quartz is only found in the finest size fraction (2—4 cm diam.) of the samples analyzed, in which it occurs in small quantities only. The Lower Terrace locally contains considerable quantities of shale pebbles which are subject to rapid decomposition and which rapidly disappear farther downstream. These, and some other pebbles present in only very small quantities, as for instance blue-black limestones, have been assembled into a "Rest group"; they must have been supplied by Carboniferous rocks. The present bed of the river contains those shale fragments to a greater extent; moreover the present bed is characterized by the abundant presence of waste from the coal washings of the mines of Barruelo. The sediment therefore has a characteristic all-over black coating. The analysis G 9 was carried out on a part of the Lower Terrace which is obviously exposed to inundation at extreme high-water times (fig. 33); it is situated thus in the boundary zone between the flood plain and the Lower Terrace. Coal waste also is richly present, but, of course, mainly in sand dimensions.

The grain size of the gravel analyzed has a top in the 4—8 cm interval, only two samples having a modal class of 8—16 cm. The analyses G 33 and G 33A were made at the same point of the Matabuena terrace part; G 33 on the finer grained gravel with a 4—8 cm top fraction, G 33A on the coarse pebbles with modal values of both 8—16 and > 32 cm diameter.

Roundness of pebbles

The roundness of the pebbles is represented graphically in fig. 34, which is again so composed that left of the Y-axis the percentage of recently broken pebbles is plotted; right of the Y-axis the roundness indices of the normally worn pebbles are plotted, so that the total right of the Y-axis amounts to 100 %. The lines connecting the left column with the 0—100 index interval of the "normal" graph have no graphical significance and only serve for indicating the curve to which the plotted percentage "rec. fract." is related. In fig. 34A, curves 119 and 121 correspond to the HR terrace level; curve 118 represents the MR level. In fig. 34B, the LMR level is represented by curve 125, and the Lower terrace by curves 120 and 123.

As far as possible the measurements were carried out on quartzites only; in some cases not enough quartzite was available and in those cases hard quartzitic sandstones and the hardest Triassic conglomerate pebbles were also taken into consideration. As was said in Chapter I, special care has been taken that only pebbles with a hardness comparable to that of the quartzites were measured. Though the results may be slightly influenced by incorporating these other pebbles, we think they may safely be compared to those measurements that were taken on quartzites only.

Interpreting the graphs we should be aware that no Curavacas conglomerate is present here to provide great masses of already rounded quartzite pebbles, though smaller amounts of rounded quartzite pebbles are supplied from other Carboniferous conglomerate beds in the Peña Cilda region, and locally in the Barruelo environs. Angular quartzite is directly supplied by the Carboniferous quartzite beds. These two are mixed up in the sediments, which is demonstrated in particular by curve 119. In the cases of both 119 and 121, the transport distance must have been very small, as is seen from their rather low modal classes. From the high percentage of indices greater

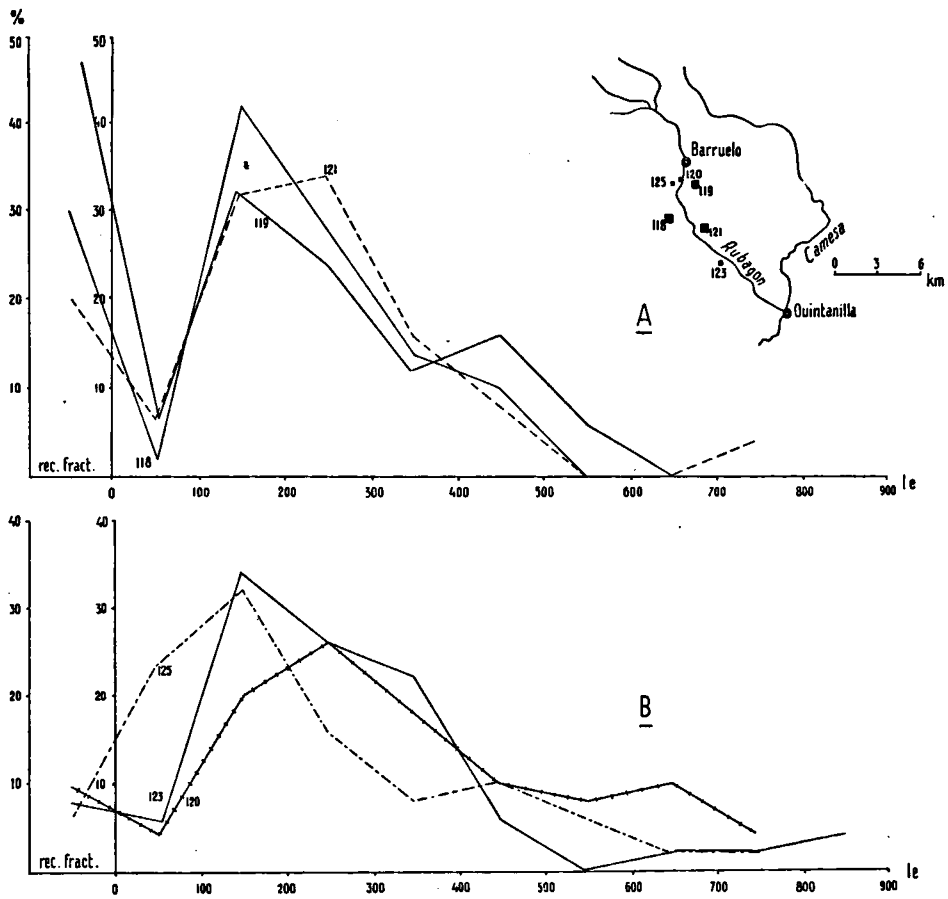


Fig. 34. Roundness of quartzite pebbles of the Rubagón terraces;
A: HR and MR terraces. B: LMR and Lower terraces.

than 300 we may conclude that periglacial influences are absent in the HP terrace sediment, and that the sediment has been subject to normal fluviatile transport over a short distance. The river must have been overcharged with sediment, and must have had a braiding character. Most probably the sedimentation took place under a temperate climate with rather strong mechanical weathering. *) The MR terrace sediment is represented in curve 118 (fig. 34A). The top in the 100—200 index interval is considerably higher than that of the curves 119 and 121, whereas the percentage of indices > 200 is noticeably smaller. From this one curve, representing the most reliable analysis (fresh sediment in outcrops on the MR terrace is very rare), little can be concluded as to climatic conditions under which the sedimentation took place. Because of the high peak in the low index interval we might conclude to a short transport, and perhaps also to a lowering of the indices of already rounded pebbles by periglacial action. But we shall have to look

*) We should keep in mind that the present climate also causes strong mechanical weathering because of the altitude of the area, the strong insolation, and hard winters.

for other arguments to conclude safely on the glacial or interglacial character of the sediment; the reader will find these arguments in the paragraph on the roundness of quartz grains.

Things are clearer in the case of the LMR level, the 15—20 m terrace. This terrace is found somewhat farther downstream than the former. The high percentage of indices in the 0—200 interval points to a periglacial climate under which the sedimentation took place (fig. 34B, curve 125). In the Lower Terrace, represented in curves 120 and 123, a seemingly abnormal fact is that the pebbles of the more upstream sample (120) are better rounded than those of sample 123, situated far more downstream. A suitable explanation for this difference cannot be given. Traces of periglacial action may be noted in these graphs, but it seems to have been less intensive than in the case of the LMR sediment.

Summarizing we may say that the roundness of the pebbles of the HR terrace points to the absence of periglacial influences in the HR time, and that probably the climate has been temperate with rather strong mechanical weathering. In the LMR and the Lower terraces periglacial influences are certainly demonstrated; later on the reader will see that a periglacial climate also ruled in the MR time.

As is seen both from the map and from the pebble analyses, the transport has taken place over a short distance only, whereas locally lateral supply of material caused a sudden decrease of the roundness index.

Grain size of sand and clay fractions

The grain size frequencies of the fraction $< 2000\ \mu$ of the Rubagón terraces are presented in fig. 35. Fig. 35 A represents the HR terrace. The sediment is very badly sorted (table 11), and has a considerable clay content. Curve 203 corresponds to the Mantalbaniega terrace part, which we do not strictly consider as a Rubagón terrace. Yet the shape of the frequency curve shows a great similarity to that of the HR terrace. The relation between the two terraces will be discussed in Chapter X.

The MR terrace (fig. 35 B) has a top of some 10 % in the 210—150 μ interval (curve 57), which must be a result of wind work, as will also appear from the shape of the quartz grains. The LMR level has a high clay and a considerable silt content; the latter must be attributed to eolian action rather than to fluviatile sorting, be it that this eolian work has only been of subordinate importance.

The curves of the Lower Terrace (fig. 35 C) are of varying shapes, with a tendency to a better sorting in the downstream direction. Sample 114 was taken in the gap of the Rubagón through the Menaza and Cabria terrace parts (cf. Chapter IX), and here an important silt content is present. Possibly this is also a result of eolian deposition.

The bad sorting of most of the samples (cf. table 11) points to important variations of stream velocity during the sedimentation. The lower two terrace levels are mainly distinct from the higher ones by the higher silt content, possibly due to eolian action which has been of local importance only.

Roundness of quartz grains in the 500—1050 μ interval

The roundness of quartz grains of the terraces is presented in fig. 36 A, B and C, where the most characteristic types for each terrace group have

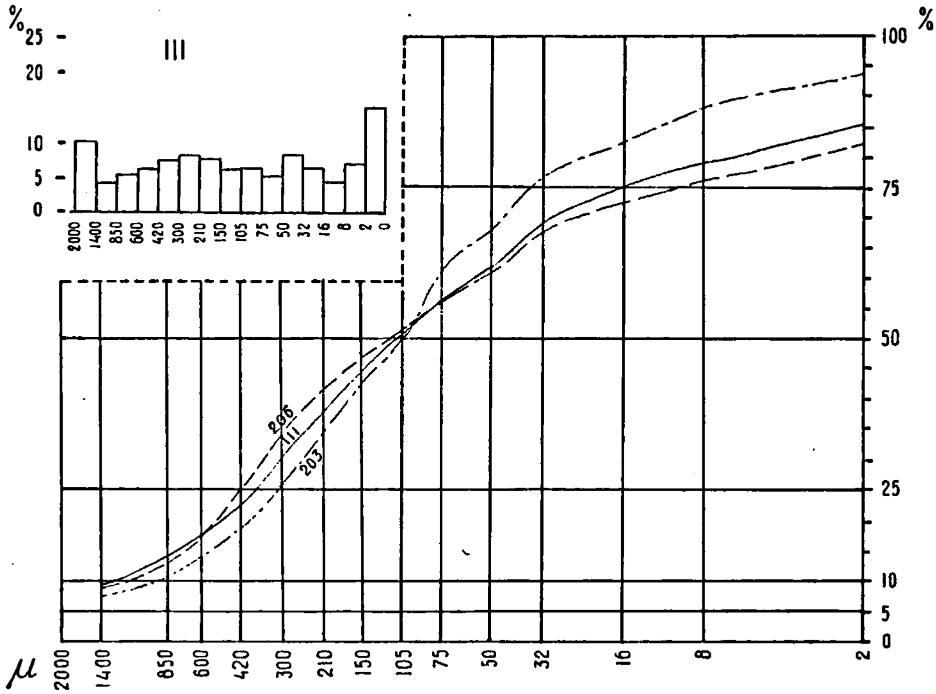


Fig. 35 A. Grain size distribution of the HR terrace sediments < 2000 μ.

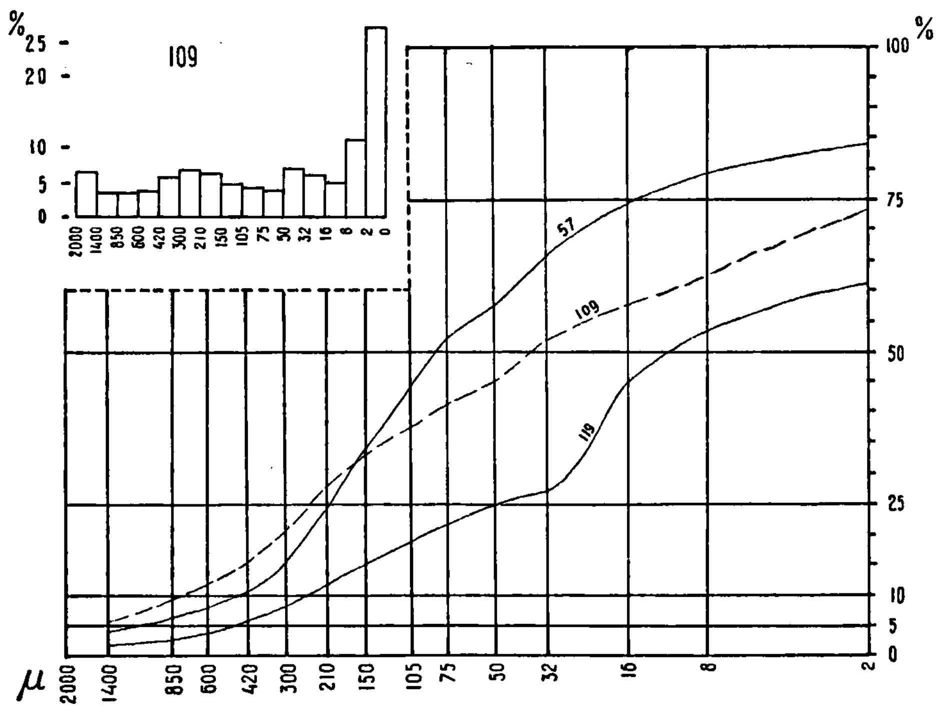


Fig. 35 B. Grain size distribution of the MR and LMR terrace sediments < 2000 μ.

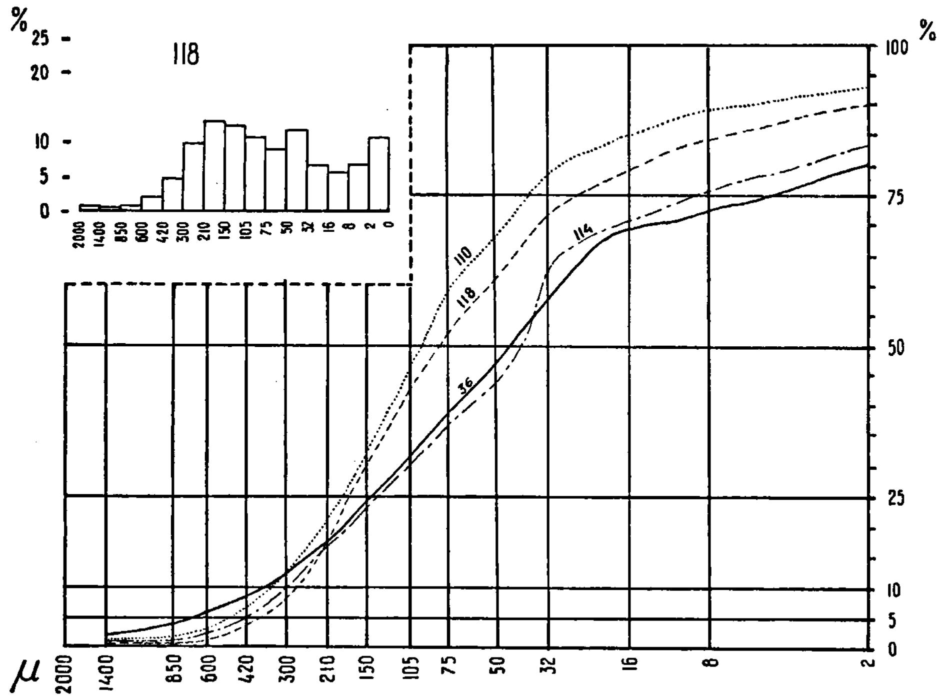


Fig. 35 C. Grain size distribution of the Rubagón Lower Terrace sediments < 2000 μ.

TABLE 11.

Statistical values of the Rubagón terrace curves

	Q_1	Md	Q_3	So	Sk
Sample:					
HR terrace					
111	360	112	16.2	4.86	.47
206	425	120	9.4	6.71	.28
(203)	314	105	35	3	1
MR terrace					
57	210	86	15.2	3.71	.43
LMR terrace					
109	250	36	—	—	—
119	50	11.4	—	—	—
Lower Terrace					
36	144	44	4.4	5.7	.33
110	188	94	38	2.23	.81
118	176	82	24	4.2	.64
114	140	40	8.6	4.04	.76

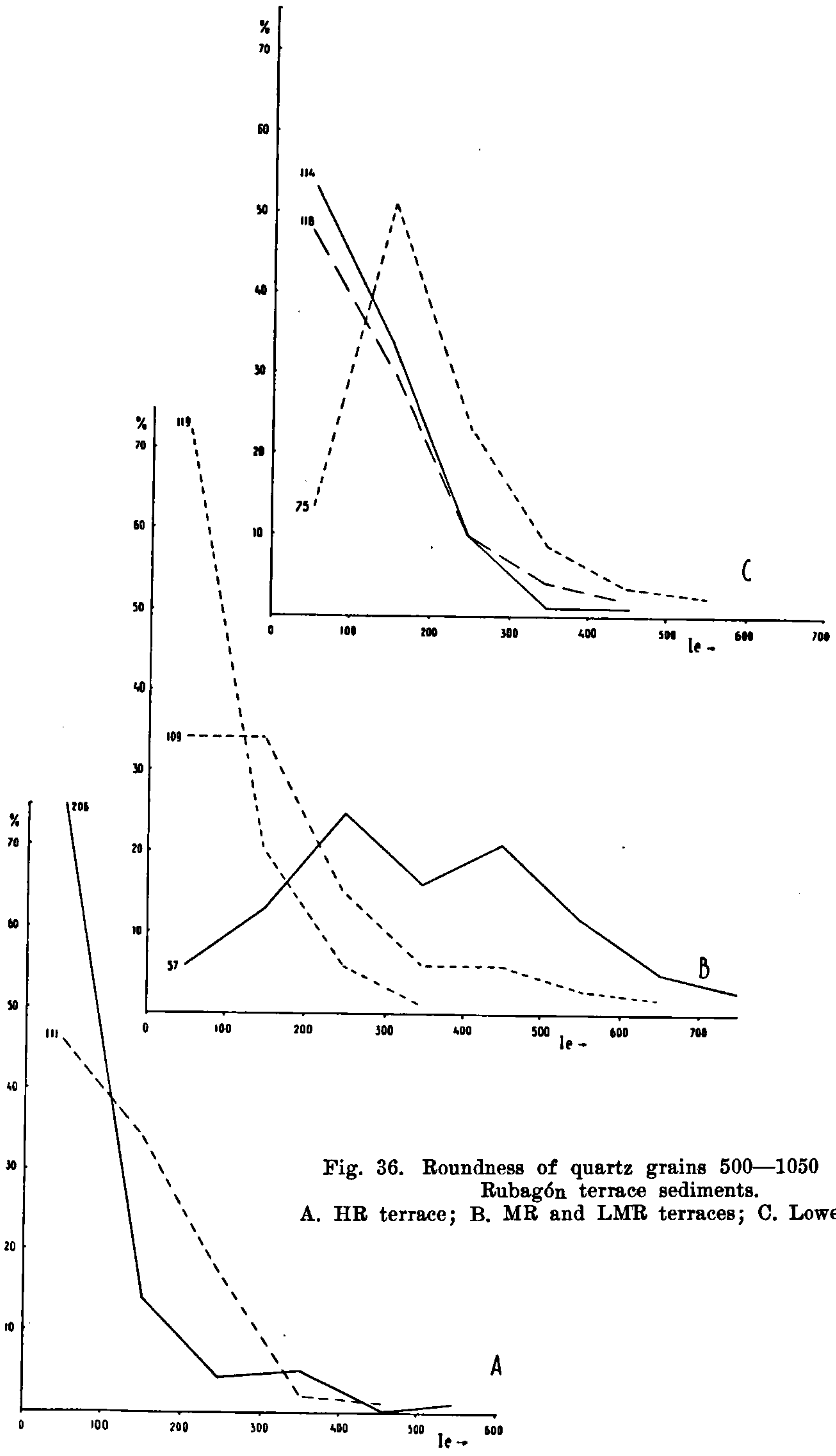


Fig. 36. Roundness of quartz grains 500—1050 of the Rubagón terrace sediments.
A. HR terrace; B. MR and LMR terraces; C. Lower Terrace.

been selected. The graphs speak for themselves, the roundness values are low in general. Though this fact in itself does not indicate a short transport *), the situation in the upstream part of the Rubagón system leads us to the conclusion that the transport distance has indeed been short.

A very outstanding exception is the MR terrace, represented by curve 57 in fig. 36 B. Here, a well-rounded sediment is present with a considerable amount of indices > 400. As is demonstrated in table 12, a very high percentage of the grains belongs to the group "frosted-rounded". It is beyond any doubt that eolian action is responsible for this phenomenon. Most probably this wind work took place contemporaneously with the sedimentation of the terrace on the valley floor of that time, for instance when the sediment lay exposed on the flood plain.

As the frosted grains are mainly found in the MR sediment the frosting cannot have been caused by chemical etching, for then it should occur to the same extent in the LMR and the Lower Terrace sediments. Moreover the grain size frequency of the MR terrace is an additional indication of eolian influence. That the wind work indeed is of MR age and not younger, is also demonstrated by the absence of wind worn grains in the lower terrace levels, except for some mixing with MR material from lateral supply to the younger LMR and Lower Terrace valley floors. If the wind action were younger than the MR time, the wind worn grains would be present in even higher percentages on the lower terrace levels, and only the top layer of the MR sediment would have been mixed up with wind worn grains. These, however, are evenly distributed through the whole of the sediment layer.

Mixing with re-worked, rounded MR material can be deduced from curves 109 (LMR) and 75 (Lower Terrace). The terrace parts nearby the Matebuena part, and downstream of it, show a clear mixing of wind worn grains with a majority of non eolian grains; this is easily seen in the graphs and in table 12.

TABLE 12.

Mean roundness and shape of quartz grains 500—1050 μ.

Terrace	Sample	mean Ie	Not rounded		Rounded	
			not frosted	frosted	not frosted	frosted
HR	111	94	90	6	1	3
	206	52	93	7	—	—
MR	57	339	42	14	1	43
LMR	109	155	71	13	—	16
	119	47	85	5	—	10
Lower	118	100	88	2	1	9
	75	169	86	6	1	7
	114	77	88	3	3	6

Eolisation in the LMR and Lower Terrace times may also have occurred, as was discussed in the preceding paragraph, but it must have been of subordinate importance. And as we pointed out above, a good deal of the grains "rounded, frosted" in these two levels may have been derived from the original

*) Kuenen (1958) demonstrated that even after a rather long fluviatile transport the roundness values of quartz grains remain low.

MR surface, some of them having been broken by the new fluviatile transport. A certain amount of the grains "not rounded, frosted" may have been etched by chemical attack; perhaps the presence of limestone causing a higher pH of the ground and river water, may have had some influence. The amount of these grains, however, is very small.

From the granulometric and morphometric data we can conclude that eolian action in the Rubagón valley, though strictly limited in time and place, has been of more importance than in the Pisuerga area. The eolisation of the MR terrace was by far the strongest; it is clear that it must have been caused by a periglacial climate, in which most of the water was frozen except during superficial thawing, and in which the wind action was largely facilitated by the sparseness of vegetation.

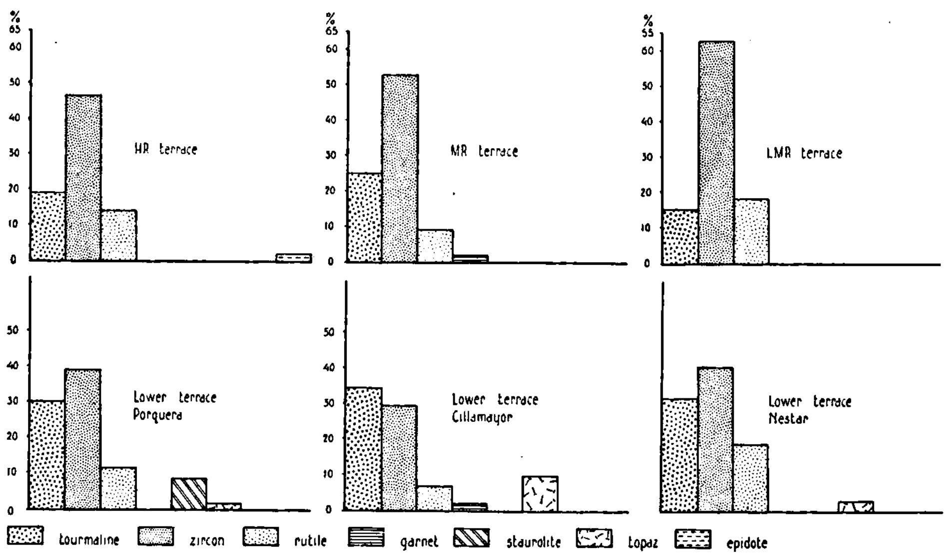


Fig. 37. Averaged heavy mineral compositions of Rubagón terrace sediments.

Heavy mineral composition

The results of the heavy mineral analyses are listed in table 13, in pocket at the end of this paper; the averaged compositions are represented graphically in fig. 37. The HR terrace is characterized, besides of a prevailing tourmaline-zircon-rutile association, by the absence of staurolite, which is rather surprising in a region bordered on most sides by Triassic rocks, since in Chapter III we saw that the Triassic is generally rich in staurolite. Perhaps the staurolite content may be limited to some particular layers in the Triassic, which did not supply the sediment on the HR terrace.

The MR and LMR levels also show a tourmaline-zircon-rutile association, with abundance of zircon. Here, too, the complete absence of staurolite is rather striking.

The Lower Terrace is equally characterized by a tourmaline-zircon-rutile association, but here other minerals are also present: first of all topaz, further some staurolite and garnet. The topaz only occurs south of Cillamayor, just at the site where a delle from the west, described in Chapter VII, debouches on the Lower Terrace. It is noteworthy that the delle originates in the Wealden region of Matamorisca, exactly in the region where the Wealden contains a considerable amount of topaz (cf. Chapter III). The topaz content of the Lower Terrace is thus explained by a supply from this delle which indicates also that in the Lower Terrace time considerable transport through this — presently dry — valley took place. Already at Nestar the topaz content has decreased to some 3 % because of the mixing up with an abundance of non-topaz containing sediments.

In the Rubagón basin, just like in the Pisuerga area, granular variations, due to the size difference of tourmaline and zircon grains, are obscured by dominant primary variations, probably as a result of differences in supply.

Conclusions

The division into four terrace levels as made in the beginning of Chapter VII appears to be justified by the sediment analyses.

The HR terrace sediment has been deposited under a temperate climate in which no periglacial action took place; weathering provided more debris than could be transported by the river which therefore took a braiding character. This is also illustrated by the bad sorting of the sediment, which points to great variations in stream velocity. From the thickness of the sediment and its considerable lateral spreading we conclude to a rather long period during which the sedimentation conditions remained more or less constant.

The Middle terrace levels also have been deposited under great variations of stream velocity, but these sediments show clear traces of periglacial influences.

The same may be said of the Lower Terrace; this is emphasized by the debouching of various dellen on to the Lower Terrace level.

As for the heavy mineral analyses, the same compositions, with minor differences, as of the Pisuerga terrace samples were found. The presence of topaz on the Lower Terrace is a proof for a former supply through one of the largest dellen from the Wealden region near Matamorisca.

CHAPTER IX

DESCRIPTION OF THE CAMESA TERRACES

The third group of terraces that will be treated in this paper are the terraces of the Rio Camesa. To the north and east the Camesa system is bordered by the Ebro drainage area, which puts the Camesa into an extraordinary position, the Ebro system being cut down deeper and eroding faster than the Rio Camesa.

The Camesa region differs in many respects from the Pisuerga region, with the Rubagón area as an intermediate. The topographical heights of the three rivers differ considerably, as is illustrated by the heights of the points where they leave the mountain core:

the Pisuerga at Cervera	1000 m
the Rubagón at Cillamayor	950 m
the Camesa at Mataporquera	915 m.

The area drained by the Camesa is much larger than that of the R. Rubagón, the latter being a tributary of the former.

Yet the terraces of the R. Camesa are less complicated, only one level being present besides of the Lower Terrace. Locally some traces of intermediate levels are found but these are quite negligible.

The HC terrace

The highest terrace level will be called the *HC (High Camesa) terrace.* The reader is referred to fig. 38, where a longitudinal profile of the Camesa with the projections of the terrace parts and their numbers corresponding to the text, is represented. An important tributary is the Arroyo de la Canal which is particularly interesting from a morphological point of view. The longitudinal profile and its relation to the R. Camesa curve are also shown in fig. 38.

As considerable height differences occur in the surfaces of some terrace parts, we have indicated their mean levels with drawn curves. Dotted lines above them give an impression of the projection of the highest points of the terrace surfaces. It should be noted that the distance between dotted and drawn curves does *not* correspond to the thickness of the terrace sediment. No traces of sediment were found upstream of Mataporquera; their most upstream occurence is situated just west of Mataporquera, that is on the *Mataporquera terrace part* (1). Here a long ridge extends all along the present valley of the Rio Camesa with a relative height of 60—75 m, that is an absolute level of 975—990 m. After an interruption by a valley of a brook the ridge continues as far as the valley of the Arroyo de la Canal near Cuena. The southern part of the ridge is somewhat lowered by erosion, but it remains always at a relative height of over 60 m. The ridge is covered with a terrace sediment varying in thickness from almost 0 at its northern part to 5 or 6 m farther downstream.

To the west of the ridge a remarkable "flat" region is found, formed by large numbers of dellen and of water carrying brook valleys lying between limestone hills, all of about the same height, which is lower than that of the terrace cover. So one may suppose that the terrace cover has had a greater extension to the west and probably also to the east where another extended plateau is still present (cf. map 1). But any remnants of terrace sediment in these regions have disappeared completely, if ever they have been there.

After passing the valley of the Arroyo de la Canal near Cuena, the continuation of the Mataporquera terrace part is found as the *Menaza terrace*

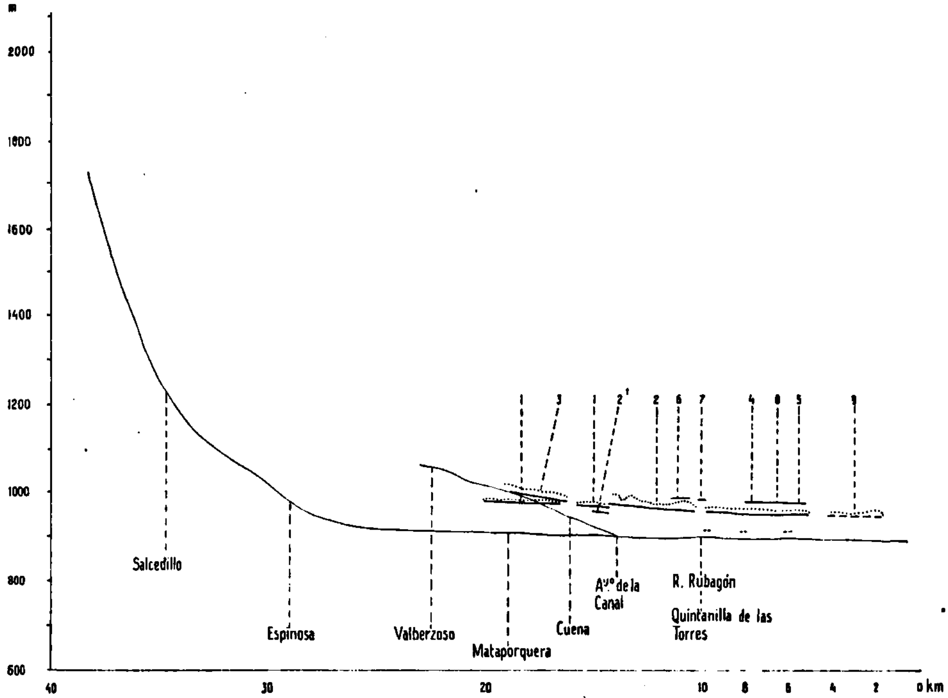


Fig. 38. Longitudinal profile of the Rio Camesa, with projection of terrace parts.

part (2). This is a very extended plain (more than 4 km long) with a locally undulating surface, mainly caused by shallow dry valleys (dellen) and young gullies. The terrace surface forms part of the present divide between the Rubagón and Camesa drainage areas. Locally relatively considerable height differences occur but the mean height of the terrace surface varies between 980 and 960 m, that is a mean relative height with respect to the R. Camesa of 55—75 metres.

The La Robla railway having to pass over the divide between the Camesa and Rubagón areas, mounts the Menaza terrace part at Cuena, along the slopes of the valley of the Arroyo de la Canal. The railway partly runs through a cutting into the terrace sediment at different levels, and at some places good outcrops are present (fig. 39). In this figure the outcrop localities are indicated by the symbols A—F and the small cross bars indicate the points, projected on this line A—F. The outcrops along this line lie below the terrace surface, on the valley flank. It is evident that the railway first cuts into the lower level, and afterwards, mounts to the real Menaza terrace surface which here, at its extreme northwestern outliers, reaches heights of up to 1000 m. The thickness of the sediment shown in the profiles is up to 10 m but that is not the whole thickness of the sediment, only a part being exposed.

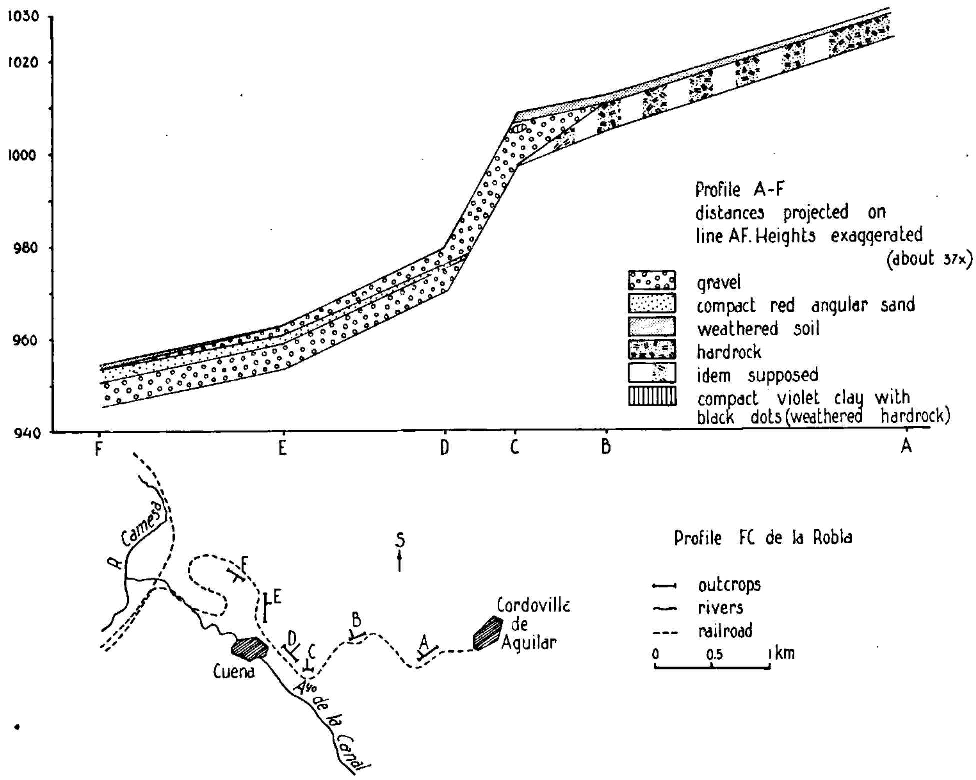


Fig. 39. Schematic section along the outcrops of the La Robla railway, near Cuena.

Now the problem rises if from this profile we might conclude to a total sediment thickness of over 40 m, into which an erosion step has developed at the lower level we discussed above, or that two terrace surfaces are present at different levels. The following arguments will serve as a proof that the latter is the case.

The deposit of the lower terrace level, which will be indicated as the *Cuena terrace part* (2) lies at a height of 960 m; it has not come downslope by creep or solifluction from higher Menaza terrace parts above, as the pebbles of the outcrop show a distinct imbrication. If the material would have been transported downslope, such structures certainly would have been destroyed.

The Cuena terrace part lies at the flank of the valley of the Arroyo de la Canal, and it was found to be certainly *not* the continuation of the Mataporquera terrace part, and neither of the Menaza terrace part, which here lies at heights between 980 and 1000 m (cf. fig. 40).

The Mataporquera part continues, as we remarked, in the Menaza terrace part, which has another branch in the Arroyo de la Canal valley, as will be discussed later in this paragraph.

Moreover, neither north nor south of this Cuena terrace part, a sediment thickness of over 15 metres has been recorded, which makes it very improbable that here a sediment thickness of over 40 metres would exist.

Thus, it will be clear that the Cuena terrace part should be considered as an alluvial fan, deposited by the Arroyo de la Canal near its outlet into the Camesa valley, in a time after the HC deposition. The analyses of the sediments (Chapter X) are in accordance with this point of view.

In the sediment of the Cuena terrace part, a layer of angular, reddish, strongly indurated sand is found (fig. 39), which can readily be recognized

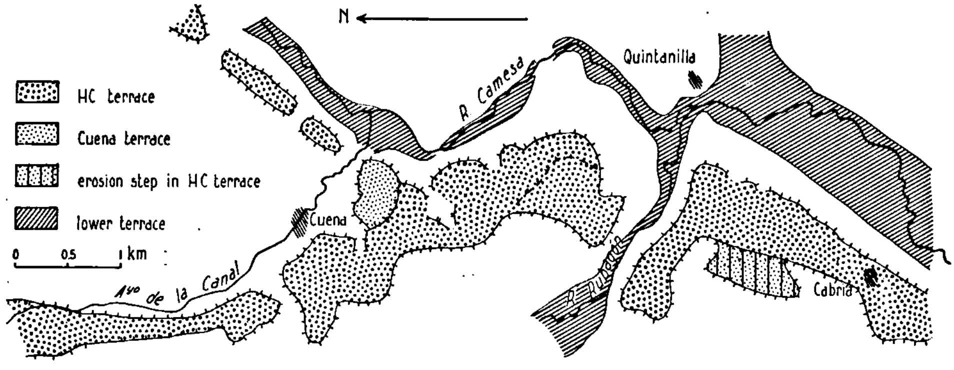


Fig. 40. Cuena terrace and HC terrace parts.

as derived from the Triassic rocks. The layer dips with about the same amount as the bed of the Arroyo de la Canal, and is absent in the Menaza terrace sediments. This is also a strong argument in favour of our point of view that the Cuena terrace part is a remnant of a deposit of the Arroyo de la Canal.

Only the sediment lying on the slope between the Menaza part and the Cuena terrace part (cf. fig. 39), should be considered as HC sediment transported downslope by soil creep and solifluction.

As we follow the Arroyo de la Canal upstream, it appears that the Menaza terrace surface continues in the valley at the same level whereas the altitude at which the brook flows rapidly increases, so that after about 1½ km it flows in the same level as the extension of the Menaza terrace which, upstream of this point, is no longer a terrace but a valley floor. Seen in the reverse direction, that is the downstream direction, we can say the Arroyo begins to incise half-way the valley into what thus far was its own valley floor (fig. 41). Undoubtedly the terrace along the Arroyo de la Canal must be considered as one of the branches of the HC terrace; the sediment contains, besides a majority of Triassic pebbles, a notable percentage of quartzite pebbles which also must have been provided by the Triassic (cf. Chapter X). The sediment has only been submitted to a very short transport. Its thickness increases from some 3 metres in the north to 10 m at the southern end of the terrace surface along the valley of the Arroyo de la Canal.

In fig. 38 the downcutting of the Arroyo de la Canal is also demonstrated.

The continuation of the Menaza terrace within the valley of the Arroyo is indicated with the symbol 3.

The Menaza terrace part continues southward as far as the Rubagón valley, at an absolute height of 960—980 m, that is at 60—80 m relative. It is covered with a thick layer of terrace sediment, the thickness being at most places over 10 m. The sediment consists of a mixture of Triassic pebbles (sandstones and conglomerates) and quartzites.

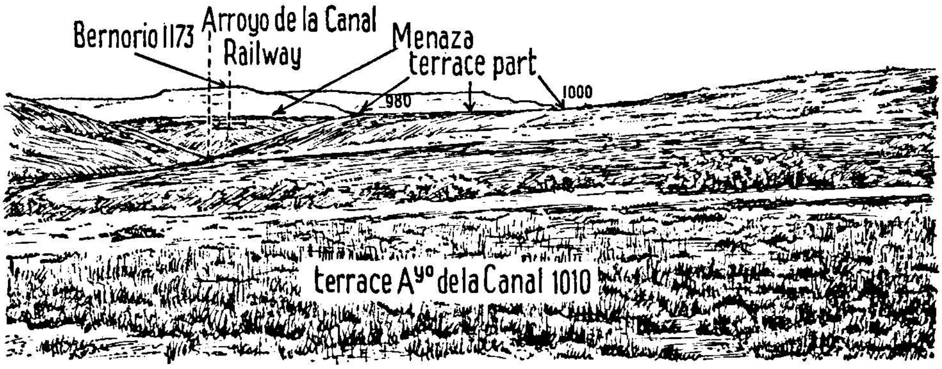


Fig. 41. Arroyo de la Canal and Menaza terrace parts seen to the S from the valley of Arroyo de la Canal.

South of the Rubagón valley the Menaza terrace part finds its continuation in the *Cabria terrace part* (4) (fig. 42), which lies at altitudes of 940—960 m, that is at 50—60 m relative. At various places the thickness of the gravel deposit could be established and was found to be 12 metres. The sediment again consists of Triassic sandstones and conglomerates and of quartzites. The terrace part extends over more than 4 kilometres along the Camesa valley, and finds its end northeast of Aguilar de Campóo. On the western end an erosion step is found where the cover sediment has been carried away (fig. 40). East of the Camesa valley the continuation of the Cabria terrace part is found in the *Porquera terrace part* (5) south of Porquera de los Infantes. It lies at the same level, at a relative height of 60 m, and is covered with the same

Fig. 42. Cabria terrace part and Las Tuerces gate seen to the South.

sediment with a thickness of 10 m at most. Farther southward as far as Villallano, at the the same altitude as the Porquera terrace part, extends a row of hills which may be very well the continuation of this terrace. However, detailed investigations have not been carried out there as yet, so that we cannot say anything further on this subject. In the Las Tuerces (1095 m) region, which is visible as a kind of gate in fig. 42, no traces of a continuation of the terrace have been found. Possibly some are present farther southward in this folded zone, but that is far outside of the region investigated by us. The possible continuation of the terrace is indicated in fig. 38 as (9).

The Matalbaniega terrace parts were discussed in Chapter VII; the three parts are indicated in fig. 38 by the numbers (6) for the northernmost part, (7) for the Matalbaniega terrace part, and (8) for the southernmost part. The reader will remember that a sedimentary cover of 10—12 m thickness was found, the height of the surfaces being from 995 m in the north to 980 m in the south. From the gravel analyses we shall see (Chapter X) that there is a narrow relationship of the Matalbaniega terrace parts with the HC terrace, most probably the Matalbaniega terrace parts belonging to the HC level itself.

Traces of intermediate terraces

Only one somewhat younger terrace is found near Cuena at the Arroyo de la Canal, as was discussed in the previous paragraph.

Further, on the western slope of the Cabria terrace part an erosion step was found at some 10—15 m below the terrace surface. It is bare of pebbles and is obviously caused by downslope transport of the terrace sediment to the brook valley west of it. It has, therefore, no genetic relationship with the Camesa terraces, and hence it is only of restricted local importance (cf. fig. 40).

Between Cabria and Porquera de los Infantes at some 20 m over the present Camesa valley floor, gravel was found on both sides of the river. If ever a terrace has been present at that place, nothing has been left of it; it is not impossible, however, that the pebbles are a remnant of solifluction material having come down from the HC terrace lying above it. These being the only indications of possible intermediate terraces, they need not be discussed any further.

The Lower Terrace

Not only in the nearly complete absence of intermediate terraces, but also in the nature of the Lower Terrace, the R. Camesa differs from the Pisuerga and the Rubagón.

It was noted already that the Camesa has a remarkably low gradient, much lower than that of the two other rivers (fig. 38). As a consequence in times of abundant rainfall and in spring after the snow melting, the capacity of the main valley is not sufficient to carry off the largely increased amount of water supplied from the upstream region and by the tributary brooks, and the result is that the whole valley floor is inundated, and all that might be considered as a Lower Terrace, disappears under water or at least becomes marshy.

So a real Lower Terrace is absent though probably the valley floor corresponds, as to its age, to the Lower Terrace of the other rivers; there is no difference in level between the Camesa and the Pisuerga Lower Terrace at the point of junction south of Aguilar de Campóo, so that at this place, and little upstream of it, the Camesa has performed some incision into its Lower Terrace.

If we start wandering along the bed in the downstream direction, we see that the river originates in a glacial cirque on the Peña Rubia, which forms part of the Sierra Hijar. The river comes down steeply, and near Espinosa it enters a remarkable zone with a low, undulating relief type (fig. 43). The surface of this plain consists of solid rock, not of sediment, except for some minor deposits. It has developed below the level of another planation surface

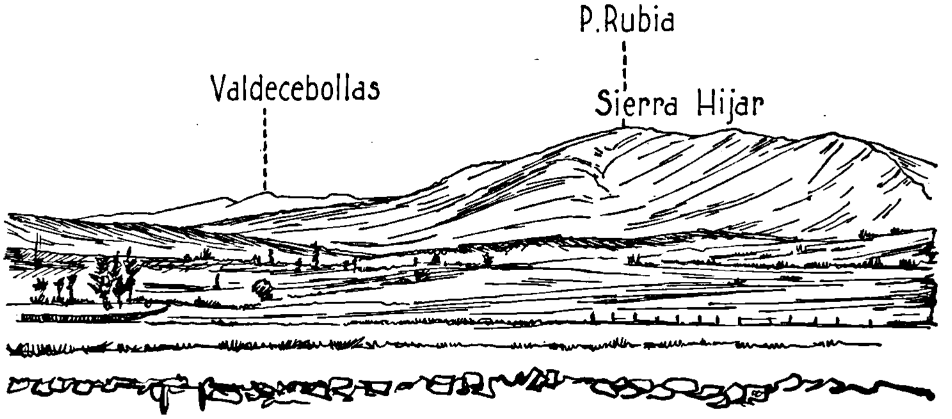


Fig. 43. Camesa valley plain at Espinosa seen to the West.

(cf. Chapter XI), and it obviously is the result of lateral planation in the soft Keuper and Permo-Triassic rocks, which are very sensitive to denudative planation. This must have started from the Camesa valley and have worked backward by slope recession. The process was facilitated by the existence of the higher planation surface and went on as the Camesa incised into this surface.

A marshy region, existing even in the dry summertime, illustrates the insufficient drainage capacity of the river.

From here, the river takes a more southward direction, passing through a gap and entering into a following zone with low relief. This is the Mataporquera planation surface (cf. Chapter XI), through which the river passes at a lower level. The Camesa valley locally is broad and shallow, but it has not developed to such a planated surface at a lower level, as is the case in the surroundings of Espinosa. Here, too, a marshy region is present; both marshes are indicated in map 1.

At Mataporquera the course of the river changes 90° in direction, and here a sediment-covered valley floor is found, bordered on both sides by rather steep slopes. This type of valley floor continues towards the confluence with the Rio Pisuerga south of Aguilar de Campóo, gradually widening to considerable width south of Quintanilla, though always sharply bordered.

Pebbles are present but are hard to find because of the peaty and muddy material they are embedded in. No analyses could be made of them. Because of the low gradient, the river describes free meanders nearly everywhere along its course downstream of Mataporquera. In the regions upstream of Mataporquera meanders are also present, though less numerous.

CHAPTER X

SEDIMENTARY PETROGRAPHY OF THE CAMESA TERRACES

LOWER TERRACE

In the preceding chapter we remarked the extraordinary conditions in the "Lower Terrace" of the R. Camesa. The pebbles are embedded in the marshy valley floor, and outcrops are lacking so that no pebbles for analyses could be gathered. For the same reason it was not possible to take reliable samples for analyses of the finer fractions. So, by force, the sedimentary petrography of this Lower Terrace had to be more or less neglected, and only some general remarks can be made.

The sediment may be expected to be badly sorted; it is rich in organic matter. In general there is no doubt but the pebble and heavy mineral associations will be the same as those of the HC terrace because the supply area is the same and tributaries are scarce and of subordinate importance. Moreover the Lower Terrace is directly bordered by the HC terrace on the western bank almost over its full length, and it is very likely that earlier the HC terrace surface extended also at some places on the eastern bank of the present river, where it has disappeared since. The position of the Camesa Lower Terrace within the valley is the same as that of the Lower Terraces of the Rubagón and of the Pisuerga, and for this reason we may presume that initially the Lower Terraces of the three rivers are of the same age. The Lower Terrace of the Camesa differs from the others in that it is still flooded every winter, and sediment is then deposited upon it.

Another possibility is that erosion has destroyed the original Lower Terrace and that now, at a somewhat lower level, the present valley floor is being formed. It seems more probable, though, that the present valley bottom corresponds to the original Lower Terrace surface. In glacial times the river must have had a greater capacity than it has now, at least periodically in spring. The low gradient of the valley was sufficient for the large water masses to flow; their overcharge of sediment was rapidly deposited. The softness of the rocks which were passed largely facilitated the erosion, which resulted in an over-flattening of the longitudinal profile of the river (cf. fig. 38). In postglacial time, the quantities of available debris rapidly decreased, and so did the amount of water, perhaps to a smaller extent. Combined with the over-flattened longitudinal profile of the valley, this resulted in the disappearance of both the erosive and the transporting power of the river. Only in the most upstream region, on the slopes of the Sierra Hijar, nowadays erosion takes place, but already from Espinosa downward no traces of any recent erosion could be found. It was also observed that after heavy rainfall (and the same will take place after snow melting) all of the Lower Terrace becomes marshy and gradually is inundated, the stream velocity remains extremely low; all this is particularly valid for the valley upstream of Quintanilla de las Torres. The amount of sediment transported and deposited at the present time must be extremely small in this part, and the majority of sediments consists of stagnant water deposits.

The river describes innumerable meanders from one slope of the valley floor to the other, and the traces of ancient meanders and ox-bow lakes can be recognized everywhere along its bed. This explains also the absence of pebbles at the surface; at some depth they may be expected in more or less important quantities.

It is still noteworthy that various dry valleys, dellen of the largest type, are debouching on to the Lower Terrace just as is the case in the Rubagón valley. Other valleys at present carry water throughout the year but their cross-sections give a concave profile, just as with the dellen, which points to an important lateral supply of material. These valleys may be a result of the combined and alternating actions of corrasion under periglacial climatic conditions and of fluviatile erosion. They are found, for instance, northeast of Aguilar de Campóo and north of Cuena, furthermore at numerous places along the river upstream of Mataporquera.

The analyses of the Camesa deposits thus could be carried out on the HC sediments only.

THE HC TERRACE

Pebble associations

In fig. 44 the pebble associations of the HC terrace parts are represented graphically. The diagram must be read as is indicated on the sketchmap of the same figure. The branch from Mataporquera and the Arroyo de la Canal branch join at the Menaza terrace part; the diagram is very instructive as it shows the different supply of terrace sediment by the two principal branches. The sediment of the Arroyo de la Canal valley has, of course, a dominating Triassic component. In analysis 103 a quartzite content of some 30 % is rather surprising. It is located in a Triassic region, the ridges on both sides of the valley consisting of Triassic rocks over their full length. So a quartzite pebble supply from a Carboniferous conglomerate is excluded; moreover, the whole region upstream of this valley as far as the main divide consists of Triassic rocks. The only remaining possibility is that the sediment has been derived from a conglomerate bank of the Triassic, which must be rich in coarser quartzitic pebbles. Though we have not recorded such layers, their presence is not excluded (Nederlof, personal communication), and moreover they may have been present in the HC time and have disappeared by now. As the Triassic sediments were deposited around the young Hercynian Mountains, pebbles from a Carboniferous conglomerate may have been embedded in the Triassic series so as to form new coarse quartzite conglomerate layers.

The high Triassic content of sample 105 is quite normal. The gravel composition of the Mataporquera branch (104) again has a rather high quartzite content of some 20 % which must also be explained by supply from the Triassic rocks.

The pebble associations of the Menaza and Cabria terrace parts (36 and 37) have a conspicuous content of sandstones. Though the group "Triassic pebbles" contains both Triassic conglomerates and the easily recognizable coarse Triassic sandstones, part of the other sandstones may have been derived from the Triassic rocks as well. Another part of them could be recognized as

Keuper sandstones (the reader will remember that "Triassic" in fact refers to Permo-Triassic whereas Keuper is distinguished separately, cf. map 2 and Chapter II). The quartz is derived from desintegrated Triassic conglomerate.

In the analyses 36 and 28 also a high quartzite percentage is found. The explanation of this sudden increase in quartzite is easily given: from their

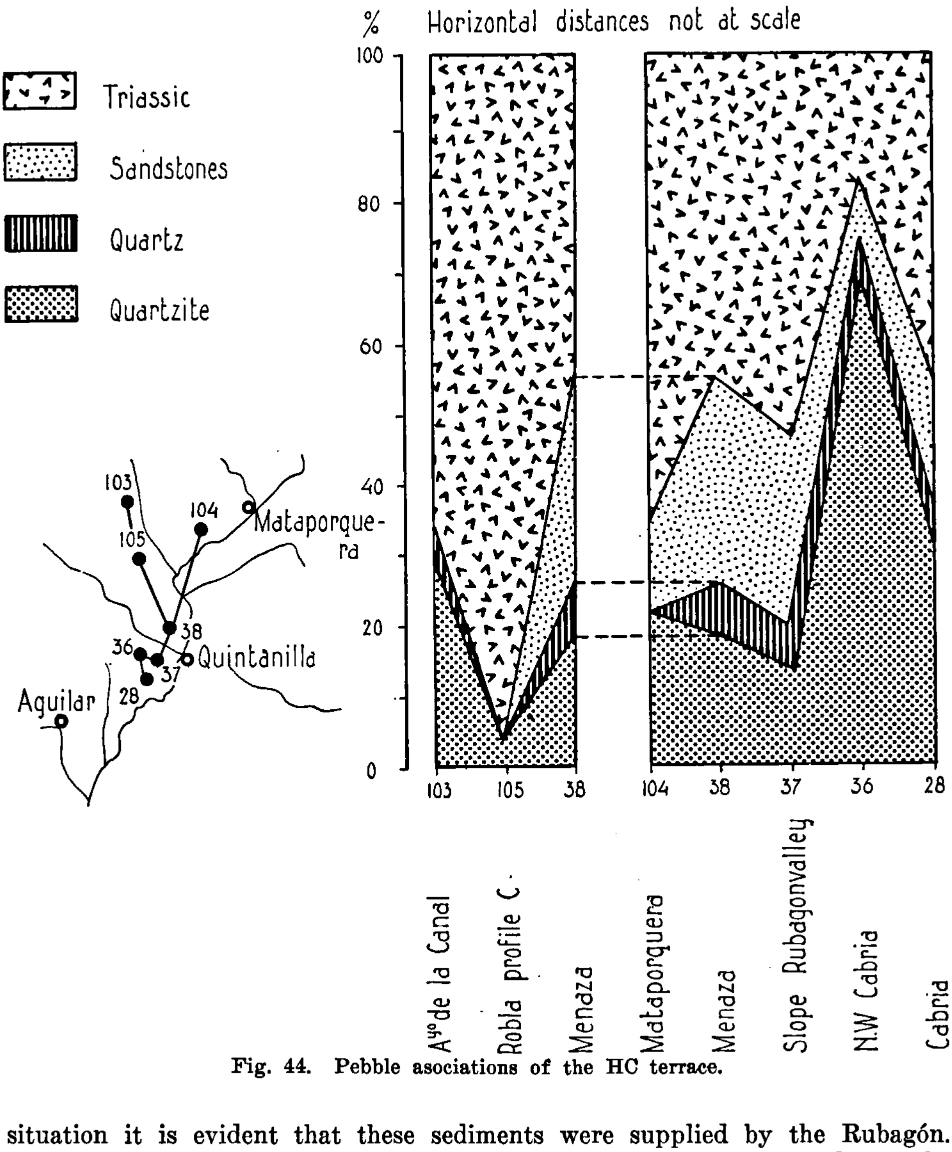


Fig. 44. Pebble asociations of the HC terrace.

situation it is evident that these sediments were supplied by the Rubagón. Anal. 36 shows the strongest Rubagón influence whereas in anal. 28 the Camesa and Rubagón components are obviously mixed up. From this we can conclude that the High-Rubagón river was a tributary of the High-Camesa river and that they covered together the piedmont plain, which will be discussed in the next chapter. The greater part of this surface seems to have been covered with terrace gravel, which is now still found on considerable parts of it.

The pebbles analyzed are of a modal diameter of 4—8 cm though coarser

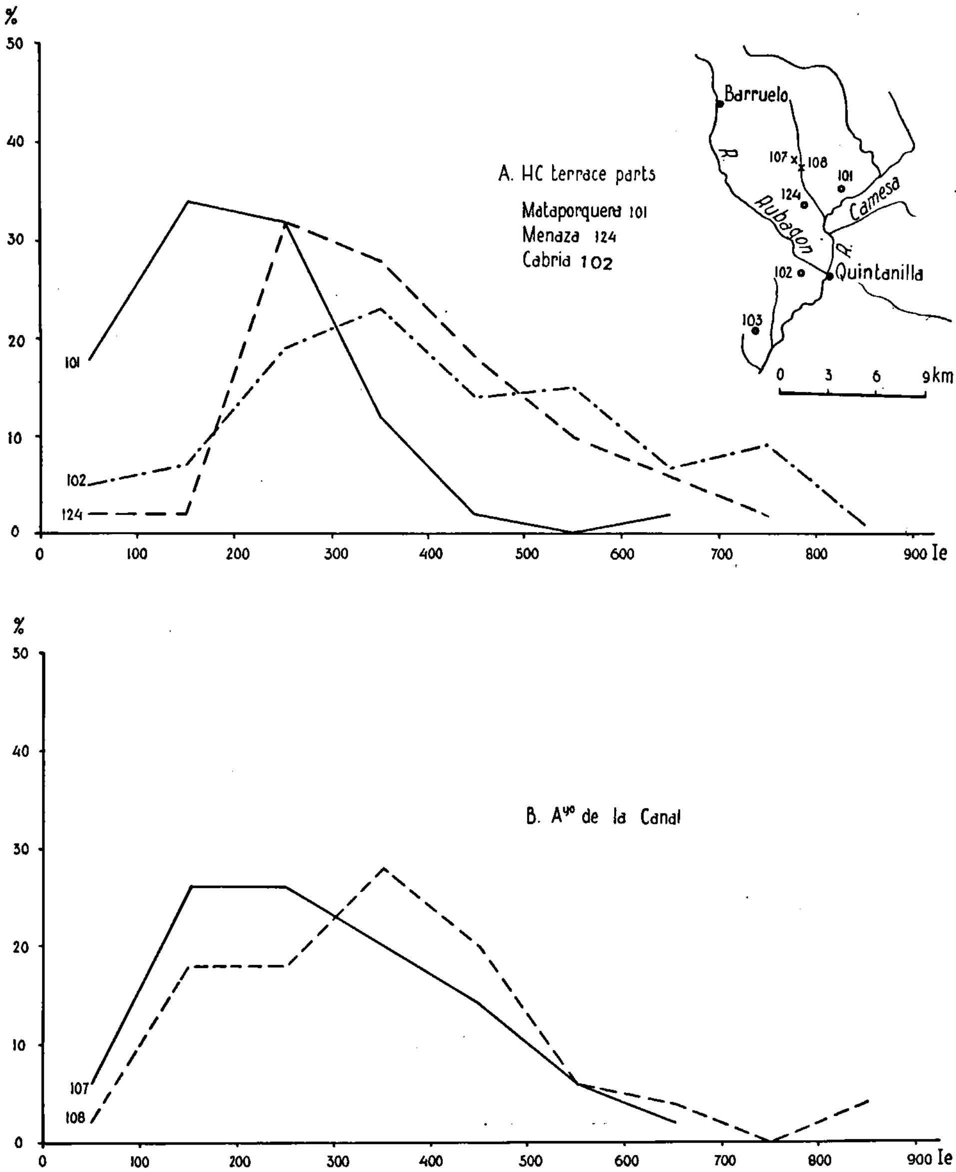


Fig. 45. Roundness of pebbles of the HC terrace and the Arroyo de la Canal terrace part.

specimens, especially in the more upstream parts, are frequent. The coarseness of the pebbles combined with the thickness and the large areal occurrence of the sediment, point to a deposition by a heavily overcharged braiding river.

It is noteworthy that the Cuena terrace part is richer in quartzite than the HC terrace. These quartzites, too, must have been derived from some quartzite-conglomerate layer in the Triassic, as they have been deposited by the Arroyo de la Canal.

Roundness of pebbles

In fig. 45 A the roundness of the HC terrace pebbles is represented by frequency curves; they give a clear illustration of the increasing roundness degree in the downstream direction. Sample 101 is the most upstream one and it can be characterized as badly rounded. In anal. 124 the roundness is considerably better, whereas 102 is a well-rounded pebble deposit. The percentage of recently broken pebbles is not indicated in the graphs; in all cases it is lower than 10 %.

The roundness analyses point to a more or less normal fluviatile wearing over a short distance with a marked increase of roundness in the downstream direction, and in which no traces of periglacial influences can be found. This means that the HC terrace was deposited, just like the HP and HR terraces, before the first occurrence of a glacial or periglacial climate.

In graph B (fig. 45) the roundness curves of pebbles from the Arroyo de la Canal are drawn. These may not be compared to those of graph A because the material considered here is somewhat different from that of the HC analyses. Curve 107 represents the terrace, 108 the pebbles in the present brook. There is hardly any difference between them, the pebbles from the present brook being somewhat better rounded which indicates their having been derived at least partly from the terrace pebbles.

Grain size of sand and clay

The granulometric analyses of the sand and clay fractions of the HC terrace sediments are represented graphically in fig. 46 A. The material is characterized by varying clay contents which never exceed 25 %. The sorting is bad to moderate, as indicates table 14. All the curves are found within a relatively narrow zone in the diagram which points to a noteworthy homogeneity. A more or less pronounced top is found in the 210—300 μ interval of all samples, except for the Matalbaniega terrace part (203) where a modal value of 11,1 % is found in the 75—105 μ interval. The sediment of the Arroyo de la Canal (207 and 208) has a grain size frequency similar to that of the other HC terrace parts.

In fig. 46 B, curve 204 is from a weathering-clay, probably from Keuper; the weathering-products are intercalated in the uppermost parts of the HC terrace sediment. In the profile of fig. 39 (Chapter IX) it is indicated as a weathering-clay.

Curves 120, 121 and 205 of this graph represent the grain size frequencies of samples from the angular, consolidated sands from the railway-cutting in the Cuena terrace. Their clay contents range from 18—24 % whereas the top fractions lie in various intervals of the sand region. The tops are somewhat more pronounced than in the pebble-matrix (fig. 46 A), though sorting is bad. The curves are spread out over a much larger area of the diagram than the samples from the HC terrace layers. The sand layers are intercalated in the pebble masses of the Cuena terrace, and thus must have been deposited simultaneously with these, by the Arroyo de la Canal.

Inasmuch as sand layers occur below the HC gravel deposits, which

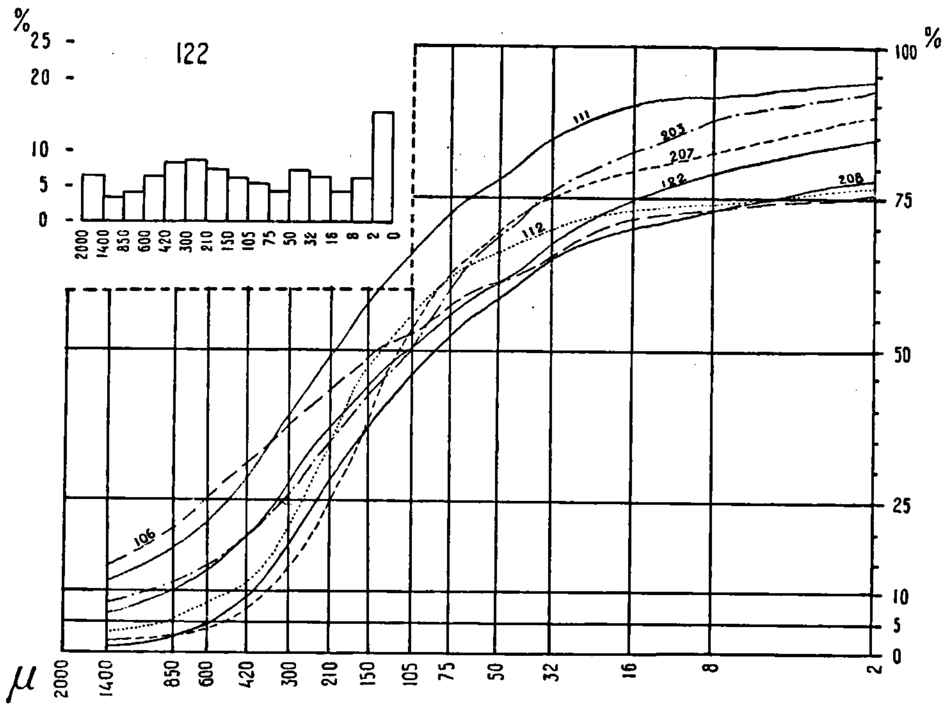


Fig. 46 A. Grain size distribution of the HC sediments < 2000μ

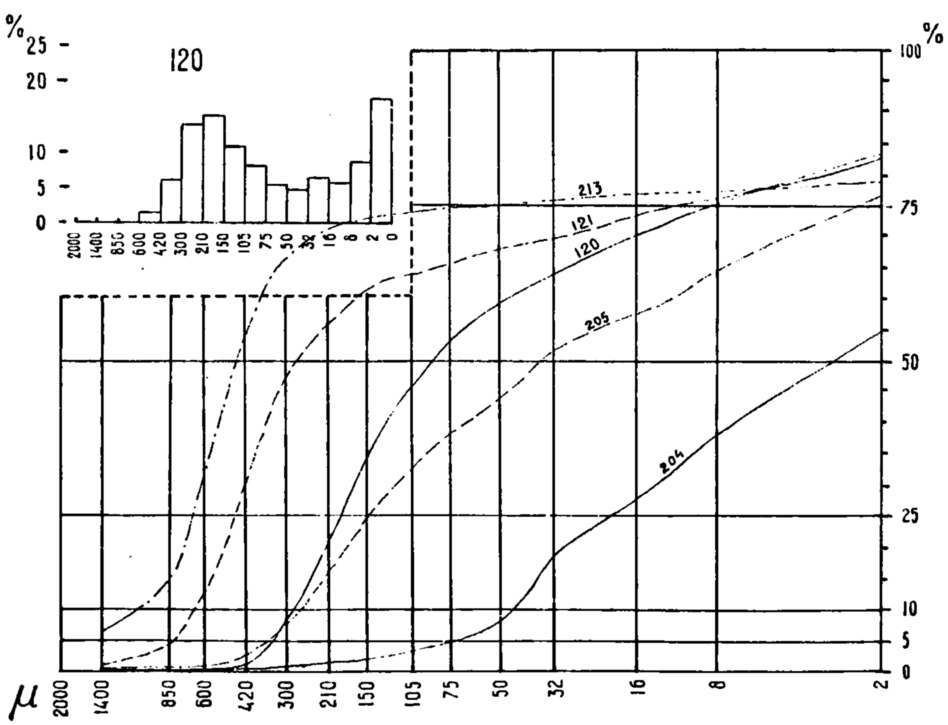


Fig. 46 B. Grain size distribution of the sand layers of Cuena and Mataporquera.

TABLE 14.

Statistic values of HC terrace and sand layer curves

No.	From	Q_1	Md	Q_3	So	Sk
	HC terrace					
208	Ayo de la Canal, upstream	240	86	4.8	7.1	.16
207	Ayo de la Canal, middle region	210	116	32	2.6	.50
122	La Robla railway profile...	330	108	14.8	4.6	.42
115	Menaza	510	210	62	2.9	.74
112	Cabria, northern part	260	132	4.6	7.5	.07
106	Cabria, central part	600	140	2.2	16.4	.07
203	Matalbaniega	320	105	36	3.0	1.04
	Sand layers					
213	Mataporquera	660	440	52	3.5	1.75
205	La Robla railway profile, Cuena terrace	152	37	2.2	8.3	.15
120		190	90	8	4.8	.12
121		470	270	10.2	6.8	.07
204	Weathered Keuper	19	2.9	—	—	—

seems to be the case in the Mataporquera terrace part, they might very well be older than the HC terrace sediment, and represent a phase in the development of the river system with more quiet sedimentation conditions. This sand, too, is easily recognized as derived from the nearby Triassic rocks. Sample 213 (fig. 46 B) was taken from this sand layer, and can be characterized as a rather well-sorted clay-containing coarse sand; the steep rise of the cumulative curve in the 850—300 μ interval is very conspicuous. This sorting cannot have been caused by eolian transport, as the quartz grains are angular for 100 % (cf. table 14).

We may call in mind the occurrence of a reddish sandy layer below the HP terrace sediments in the Pisuerga region. This material is only different in that it is finer grained, but it is also reasonably sorted; the sand layers below both the HP and the HC terrace are bi-phasic. The occurrence of such layers below both terraces point to the existence of a fluviatile system older than these terraces and quite different from the fluviatile systems which later deposited the HP and HC terraces. Quiet sedimentation conditions with considerable seasonal variations prevailed, whereas possibly the climate also may have been different.

Roundness and shape of quartz grains 500—1050 μ

In fig. 47 the roundness of quartz grains is represented. In all the samples analyzed the quartz proved to be angular. All the curves fall within the zone shown in the figure from which can be seen that the highest percentages (up to 90) are found in the 0-100 index interval, in which the indices zero have been included.

The shape of the quartz grains is read from table 15.

From this table the reader may see the extremely low values of the mean indices though a tendency to increase in the downstream direction can be observed (samples 207-203). The not rounded, frosted grains perhaps are partly a result of chemical attack, and so may be some of the grains recorded

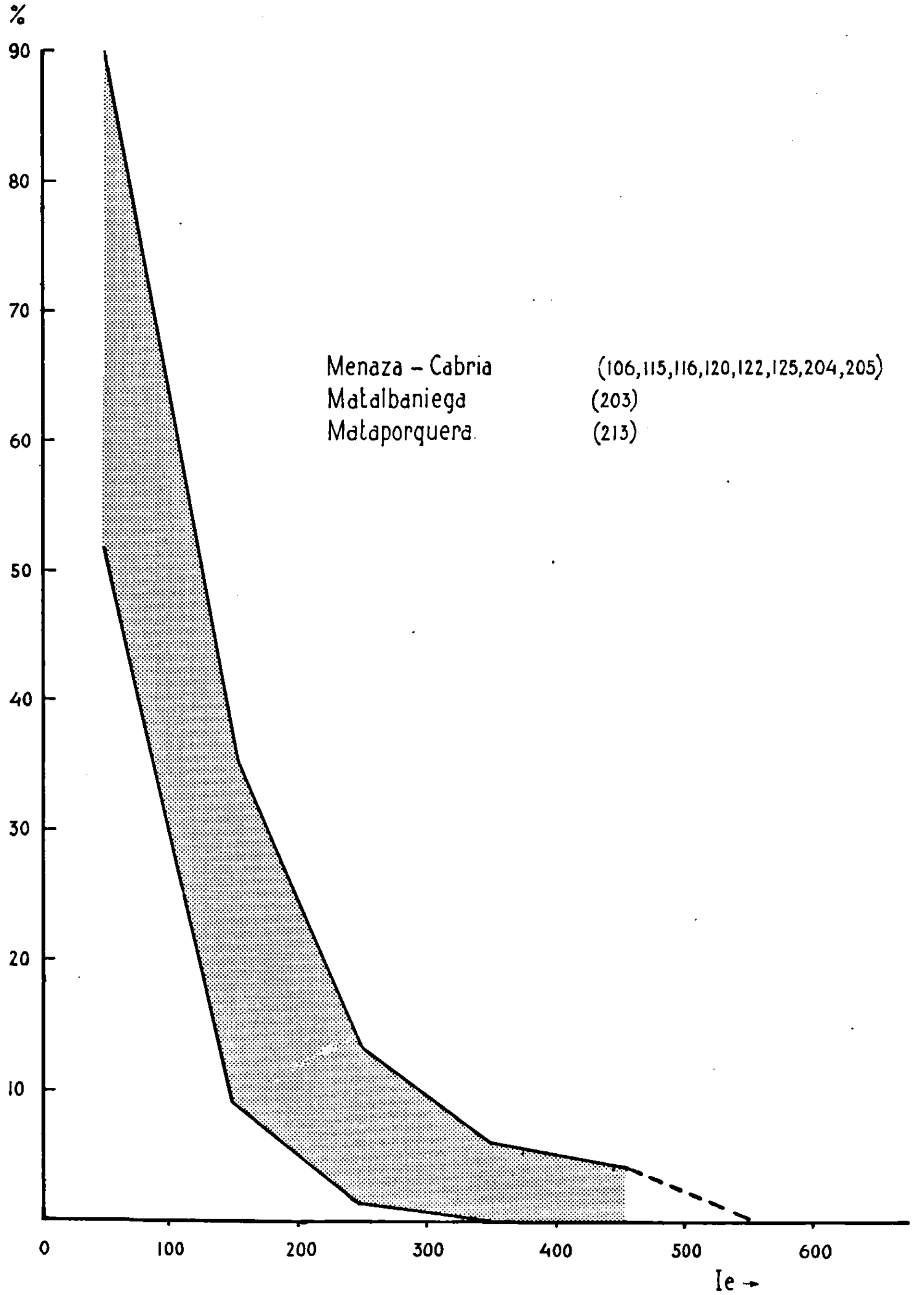


Fig. 47. Zone diagram of the roundness of quartz grains 500—1050μ ; HC terrace.

TABLE 15.
Mean roundness and shape of quartz grains, HC and Cuena terraces.

No.	From	Mean Ie	Not rounded		Rounded	
			not frosted	frosted	not frosted	frosted
207	Arroyo de la Canal	11	98	2	—	—
122	Menaza, northern part ...	47	96	4	—	—
115	Menaza, southern part ...	61	87	10	1	2
112	Cabria, northern part	86	91	9	—	—
106	Cabria, central part	69	87	1	7	5
203	Matalbaniega	66	95	5	—	—
213	Below Mataporquera, terrace part	32	100	—	—	—
121	Sand layers	44	97	2	—	1
120	"La Robla" profile	14	100	—	—	—
205	Cuena terrace	34	99	1	—	—

as "rounded, frosted", because of their low index values. Local eolian reworking obviously has influenced this sediment.

The sand layers from the Cuena terrace have been mentioned apart. They consist almost totally of grains "not rounded, not frosted".

Heavy mineral associations

The heavy mineral analyses of the HC terrace samples are presented in table 16. Just like in the terraces of the Pisuerga and the Rubagón, tourmaline, zircon and rutile are largely dominant. In all samples staurolite is found though the percentages recorded never exceed 6 %. From what has been said on the pebble associations and on the heavy mineral composition of the Triassic, it will be clear that the staurolite content must be attributed to a supply from Triassic rocks. As for the epidote present in most of the samples, we assume also a supply from the Triassic. Two specimens of a green garnet variety were recorded in sample 204. Besides of some anatase and brookite, not a single grain of any other mineral was found.

Three samples were taken from the sand layers of the Cuena terrace and from below the Mataporquera terrace part. No differences with the other samples were found.

Conclusions

Summarizing the properties of the HC terrace sediments, we see above all a dominating influence of the Triassic source material, both in the pebble and in the heavy mineral associations.

The bad sorting of the sand and clay fractions points to great variations in stream velocity during the deposition, whereas the coarseness of the pebbles and the large area over which the sediment has been spread out are also strong indications of a sedimentation under braiding river conditions. The shape and roundness of quartz grains make clear that there has been no eolian influence, whereas from the roundness of pebbles the absence of periglacial influences can be concluded.

As the Rubagón passes through the HC terrace near Quintanilla, it must have flowed at this place on the HC valley floor at the beginning of the incision phase. The influence of the Rubagón is clearly demonstrated in the pebble associations. The Matalbaniega terrace parts are found in the western part of the "piedmont plain" mentioned before (to be called the Quintanilla surface in Chapter XI), at a level of some 20 m above that of the Cabria terrace part. We may, therefore, assume that the region between the Ontañon ridge, Cillamayor, Cuena and Aguilar has been covered with sediment by a system of braiding rivers, switching and wandering laterally over great distances. Both the Camesa and the Rubagón were components of this system which shows a tendency to have glided-off in an eastward direction, as can be concluded from the higher level of the Matalbaniega terrace parts, and also from the situation of the present Camesa valley near the eastern border of the former sediment-plain.

The morphographical features of the HC terrace are similar to those of the HP terrace of the Pisuerga. They are, moreover, similar in their thickness of the sedimentary cover and in the absence of eolian and periglacial features in the sediments. They are different, however, in pebble composition and in absolute and relative height.

The HC terrace can only have been deposited before the first occurrence of a periglacial climate. The HC terrace was found to have been deposited under the same climatic conditions as the HP terrace and hence might be of equal age. The same is valid, of course, for the HR terrace of the Rubagón which debouches, as we saw, on the HC terrace.

CHAPTER XI

PLANATION SURFACES

Before treating the remnants of relatively young planation surfaces which can be observed at various places in our region, we have to discuss what other authors mention concerning older planation phases.

PRE-RHODANIC PLANATION

Stickel (1930) considered the Cantabro-Asturian Chain the result of an uplift, running W—E, of a planation surface of Oligocene or lower Miocene age. The uplift must have been considerable; remnants of the peneplain were recognized, according to this author, in Galicia and in the Asturian Mountains, from W to E, near the Piedrafita pass at 1400 m; near the Pajares pass at 1800 m., and east of the Piedras Luengas pass at 2100 m, which is in the region treated by us. The uplifted planation surface could not be followed, according to Stickel, east of Reinosa.

From the Iberic Mountains a planation phase is mentioned by Richter & Teichmüller (1933), which was active after the Savic phase through the whole of the Miocene, so as to have formed a well-developed planation surface even before the end of the Miocene. The Pontian freshwater limestones (the so-called Páramos limestones) have been deposited on most of the beveled parts of the Iberic Mountains. In the Cordillera Central, remnants of probably the same pre-Pontian planation surface are now found at the level of the summits; the age of the planation is assumed to be Miocene (Solé Sabaris, 1952). In the Pyrenees remnants of tertiary planation surfaces are found as flat summits at altitudes of over 2000 m; the age of these planation surfaces is still a point of discussion, but in general they are considered Miocene (Boissevain, 1934; Solé Sabaris, 1952; De Sitter, 1956 a.m.o.).

It appears that in most of the mountainous borders around the Meseta and the Ebro basin after the tectonical movements of the Savic phase, a Miocene cycle of erosion and sedimentation started which resulted in the "Penillanura fundamental de la Meseta" (Solé Sabaris, 1952 p. 167) which we shall call the "Principal Meseta Surface". The Meseta block itself was subject to epeirogenic movements which resulted in an updoming of the central part and a relative subsidence of the northern and southern parts. In this way the Cordillera Central and the depressions of Old and New Castile were formed. The later erosion of the mountains and the synchronous filling-up of the depressions gave rise to the formation of the Principal Meseta Surface.

As we saw that the pre-Pontian planation is represented in most of the mountain chains of northern Spain, we have to consider whether it is represented in our section of the Cantabrian Mountains or not.

In the region east of the Piedras Luengas pass, cited by Stickel as an evidence for such a high surface, we have not observed anything that looks like a remnant of a peneplain whatever its age; only the much younger

Redondo surface, to be discussed later in this chapter, is present here. We have to point out that the former existence of an uplifted planation surface may not be concluded from equal heights of the summits, and that only flat remainders may be used for tracing such a surface. (Bakker, 1948, 1956.) However, in this region no indications of any flat top or flat remainder of an erosion-surface were recorded.

We do not wish to deny that an older planation surface can once have existed in the Cantabrian Mountains, but in the region considered by us no traces have been left of it, if it has been present at all. From the foreland sediments Mabesoone (1959) concluded that before and during the Pontian the source region has always been an area with a moderate to rather low relief, which could supply sands to the foreland. In our opinion it is most probable that this phase of moderate to low relief in this part of the Cantabrian Mountains is of the same age as the Principal Meseta Surface, which means that it is younger than was thought by Stickel (1930). The planation process has not proceeded so far as to form a real peneplain in our section of the chain, though some altiplanation may have occurred. Moreover the following uplift by the Rhodanic phase may have been so great, that at least in our region the traces of the planation have disappeared by erosion.

POST-RHODANIC PLANATION

After the Rhodanic phase the erosion started anew, and a post-Pontian planation level was formed which attained great extension in and around the Meseta. At many places, a. o. at the foot of the Cordillera Central, it is developed as a pediment, the correlated screes of these pediments being the rañas, which are extensive angular sheetflood deposits. The climate at this time must have been arid or at least semi arid (Oehme, 1936 - Solé Sabaris, 1952).

Pediments south of the Cantabrian Mountains

A pediment with a raña cover is found south of Guardo at an altitude of slightly over 1200 m; it was mentioned at various times previously in this paper. Detailed investigations on it were carried out by Mabesoone (1959) who defends the opinion that this so-called "Paramo of Guardo" must be considered as a "glacis" in the sense of Mensching's (1958) and that is must be older than the raña gravel. The pediment, according to the first mentioned author, must have originated under a savannah climate with an alternation of moist and dry seasons, and date from the Pliocene. After this pedimentation the climate would have changed to more arid, though with heavy seasonal rains, during the Villafranchian; in this period the rañas would have been deposited.

Farther eastward, south of the Brezo gate, some remnants of raña deposits were also recorded, which may point to a former eastward extension of the raña of Guardo.

In the southern piedmont of the Sierra del Brezo, in the environs of Castrejón de la Peña, a "piedmont alluvial plain" was described by Kanis (1955). The surface of this plain consists of a strongly cemented limestone breccia the stones of which consist of Brezo limestone. This is the only sediment that has been recognized as derived from the Brezo limestone. In our opinion this breccia has been deposited in the same time and under the same conditions as the rañas, that is under a semi arid and arid climate with incidental heavy showers. The breccia forms a flat lying fan, dissected by deep narrow gorges, whereas younger, perhaps subrecent, steep-angled fans from the slopes of the Sierra del Brezo find their lower termination at the surface of the breccia fan. East of Cervera this piedmont alluvial plain cannot be followed, though some traces of post-Rhodanic planation were noted on the southern slopes of the "Pays Plissé".

Planation surfaces in the investigated area

In our region several planated areas are present, which are obviously of a younger age and the character of which is markedly different from the pediments discussed above *). They are situated partly in the interior of the mountain chain and partly in the region between the chain and the "Pays Plissé". From the following descriptions will be seen that they are lying at a lower level than the raña surface, and that they are related to the fluviatile system and to the softer rock types, generally speaking. The lack of angular debris in the planation surfaces is also an argument for not considering them as related to the rañas.

When discussing the HP terrace of the Pisuerga we remarked that the river(s) must have flowed through basin-like flat surfaces surrounded by mountains which caused a sudden decrease of the gradient. The occurence of such plains can be concluded from the flat base and the great lateral extension of the terrace sediment.

As will be seen later on, the remnants of planation surfaces of this type appear to belong to the same level, or perhaps to two levels of equal age. For a convenient description the separate parts will be indicated with the name of a village lying within it. In map 1 the separate parts of this planation level are indicated by letters; the same letters will be used in the text.

The Mudá surface (A).

Remnants of this surface can clearly be recognized in the zone between the "Triollo pass" and the San Julián hills (cf. map 1 and figs. 17 & 49). Its level is, in general between 1050 and 1200 m, whereas the present valley bottoms of the principal rivers are at 950—1030 m. Two separate parts of the surface can be distinguished, the boundary of which is found a little east of Cervera.

The western part lies at 1100—1200 m, with a tendency to be lower in the eastward direction. Parts of the original surface as it must have existed before the beginning of the HP terrace sedimentation, have been preserved under the terrace cover, which also protected it against erosive attack. In the parts where the sedimentary cover has disappeared, the continuation of the surface is easy to find in most places, though some lowering may have occurred. Because of its situation between mountainous zones, we may speak of an intramontane plain (cf. map 1).

The eastern part (partly visible in fig. 48) differs from the other in that it bears no gravel. Most probably this never has been deposited in this region,

*) Though there is a tendency to extend the use of the word pediment, we are inclined to restrict it to the land forms described in the preceding paragraphs, formed under an arid or semi arid climate.

because the main supply of the pebble sediment in the HP time came from the western branches of the river, and the drainage system in this eastern part will have had an east-west direction. It was directed towards the High Pisuerga which found its way to the South through the Brezo gate. As a result of the absence of a protecting sedimentary cover over the soft shales, the original

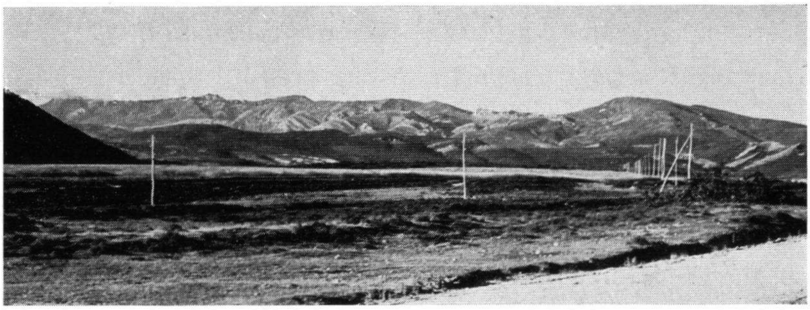


Fig. 48. Upper Pisuerga basin seen from the Boedo region.
In background: Triassic escarpment. To the right the Valdecebollas.

surface has been more lowered by erosion than in the western part so that the culminations are found between 1050 and 1100 m, though at some places heights of 1170 m are reached by more or less isolated hills, often consisting of resistant limestone. This region has been submitted to intensive dissection by numerous younger valleys so that the general character of this region, by now, is rather different from the western part. But on further inspection, as we saw, it becomes clear that in spite of the differences, both the western and the eastern part are remnants of one former planation surface (fig. 49), the height of which at the beginning of the HP time is indicated by the base of the terrace cover of the western part.

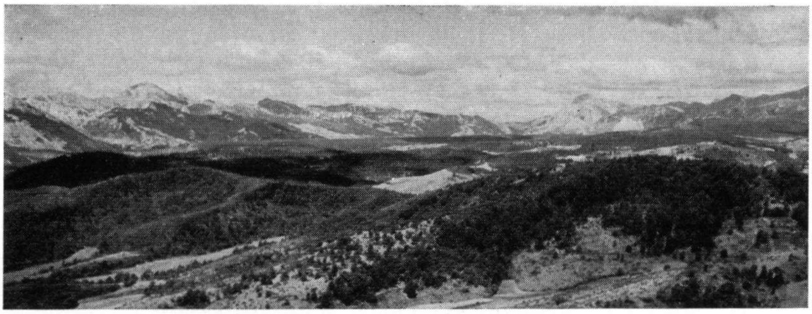


Fig. 49. Mudá surface seen from Mudá to the W. To the left: Sierra del Brezo.

The Barruelo surface (B).

In the Rubagón area a similar feature is observed; remnants of a planation level can be clearly recognized in the region south of Barruelo de Santullán (fig. 50). On both sides of the Rubagón valley the planation surface is visible; it widens towards the South so as to form, when seen on the map, something like a funnel (cf. map 1). This plain gradually rises from the HR terrace level; when describing the Rubagón terraces in Chapter VII we mentioned several times the existence of denudative landforms gently rising up from the HR terrace level. It will now be clear that they belong to the Barruelo surface. South of Cillamayor the Barruelo surface continues in the Quintanilla surface.

Fig. 50. Barruelo surface seen from the SW.

The Quintanilla surface (C).

The boundary between this, and the Barruelo surface, is formed by a low ridge of Triassic rocks, running E—W along Cillamayor. This boundary is so inconspicuous that it would even be justified as well to consider both the surfaces as a unit. The Quintanilla surface opens to an immense planated surface, into which the Rubagón and its tributaries cut down their beds. Between Barruelo and Cillamayor the remnants of the planation surface are a little lower than the eastern part of the Mudá surface; roughly speaking between 1040 and 1100 m. The Quintanilla surface, south of the mountains, lies lower, between 950 and 1000 m. It appears that the Quintanilla surface is partly bordered in the west by the Ontañon ridge, which may have been an isolated ridge within a planated area extending farther westward to the higher parts of the "Pays Plissé". It seems that the region around Salinas was a transition zone between the Mudá surface and the Quintanilla surface, the former lying somewhat higher than the latter. The surface has been preserved in its original form below the sedimentary cover of the HC terrace, that is, at this place, at altitudes between 950 and 980 m. In the uncovered region younger erosion has caused considerable height differences, the Rubagón and its tributaries having cut down into it for some 50 or 60 metres. Many of the ridges not covered by terrace gravel still show a more or less flat summit, whereas other parts have been rounded and lowered to far below the original surface. It is to be noted that in our opinion the greater part of the original Quintanilla surface has once been covered with terrace gravel, much of which has disappeared by now. This is well illustrated in the region near Matalbaniega, where nowadays, between ridges which are now bare of terrace sediment, many of the local valleys are strewn with pebbles that only can have been provided by a former cover on the hills. Sometimes individual pebbles are still found on the hills as a last remnant, thus indicating the former existence of the sedimentary cover. To the East the Quintanilla surface seems to continue as far as the Bernorio hill (1173) south of Quintanilla and the rows of hills on both sides of it. The level of the Quintanilla surface continues northeastward without a boundary, in the Mataporquera surface. The transition zone is partly visible in fig. 51.

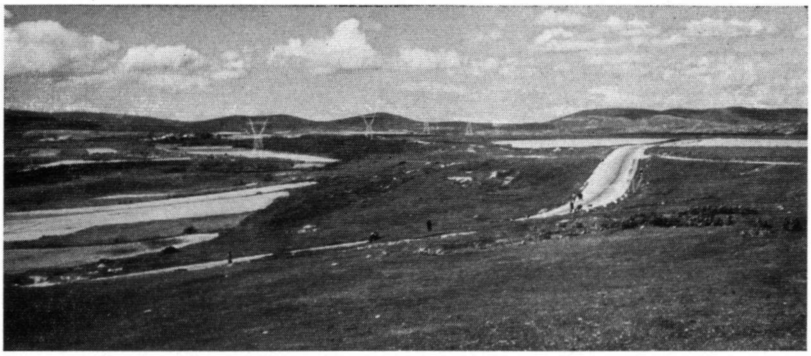


Fig. 51. Transition zone between Quintanilla and Mataporquera surfaces, seen to the N. In foregrond the Cabria terrace part.

Mataporquera surface (D).

It has partly the character of a summit level of individual hills, but east of the railway it is formed by extensive flat limestone platforms. The latter must be considered as representative for the height of the former planation surface; their heights vary between 960 and 980 m. The individual ridges and hills are found west of the railway; their summits in general are at the same level or a little below that of the just mentioned limestone plateaus. Obviously the original surface has been more dissected in this part, but it can easily be traced. Part of it is covered by the terrace deposits of the Mataporquera terrace part (cf. Chapter IX).

The Espinosa surface (E).

This surface was mentioned before, in connection with the plain into which the Camesa enters as it comes down from the slopes of the Sierra de Hijar. Part of it is visible in fig. 43 (Chapter IX) and it is found to continue eastward after the Camesa bends to the South. Its eastern continuation, however, lies at a higher level than the plain in which the Camesa flows; we could recognize this higher level also more to the West. So it seems that the original Espinosa surface lay at a level of at least 1000 m, at some places even reaching heights of over 1060 m, into which level the present Camesa cut down its bed, widening it by slope recession to a younger plain at a lower level of 940—960 m, as described in Chapter IX.

On the Espinosa surface remnants of fluviatile sediments are absent. The eastern part of the level is formed by individual limestone hills of about equal height, some of which are flat on top *). Though the surface is con-

*) They may be parts of the original Espinosa surface, but may also be a result of altiplanative processes.

nected with the Mataporquera surface, it also seems to continue eastward over the present divide between the Camesa and Ebro systems. The strong down-cutting in the Ebro drainage area makes it difficult to observe the continuation of this surface so that as yet nothing certain can be said of it.

Apart from the fossil planation surfaces described above stands the *Redondo surface (F)*, which is formed in the most upstream region of the Pisuerga as an indulating landscape at a mean height of 1200—1450 m with

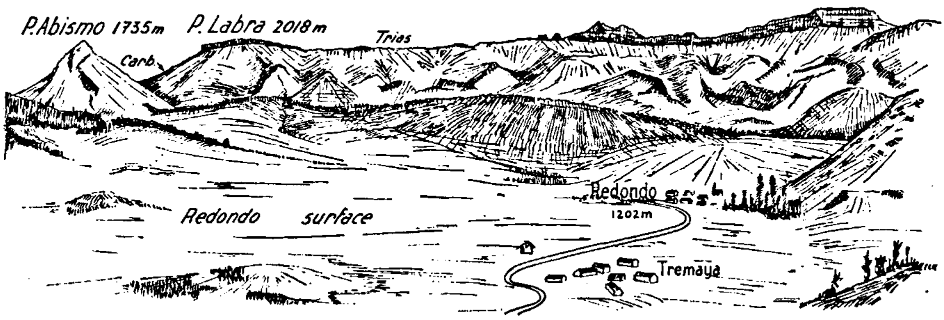


Fig. 52. Redondo surface seen to the NE.

isolated steep limestone peaks (fig. 52). It consists of two main parts, one along the Redondo branch of the Pisuerga, and the other in the Casavegas region. The slopes in the whole of the area are always gentle, except for some steep valley slopes, caused by youngest erosion. Steep slopes are also present at the limestone peaks, rising up as isolated cliffs. As the surface very gently rises up from the present valley floor level, it must be considered as a planation surface still in the course of formation. It is not possible to say when its formation started; possibly the process has been active since considerable times, perhaps since the time of formation of the other levels, the difference being that the Redondo surface has not been dissected because of its situation far upstream. The Redondo surface is also indicated on map 1.

Distribution of the surfaces with respect to the resistance of rocks

Comparing the maps 1 and 2 we have to consider the question whether the planation surfaces have any relation to the lithology of the area they are lying in, or not.

As for the *Muda surface* we see it is asscociated with the soft shale-sandstone complexes of the Culm and the Westphalian. To the South it is bordered by the Palaeozoic limestones of the Sierra del Brezo and farther eastward by the Mesozoic limestones. To the North its boundaries are formed by the Curavacas conglomerate zone and by the Sierra Corisa, also consisting of limestone ridges.

The *Barruelo surface* is also found to have a narrow relationship to the softer rock types, mainly to the Carboniferous shales and sandstones. Its eastern termination is formed by the Triassic ridge running southward from Brañosera, and also to the South the Triassic appears more or less as a boundary, though a much lower one of minor importance.

The *Quintanilla surface* has developed in the soft Wealden, Keuper and Jurassic rocks, and it is bordered to the North by Triassic rocks, and to the East by resistant Cretaceous limestones (P. Bernorio). To the southwest it is partly bordered by the Ontañon ridge which consists of the same Wealden rocks as the planation surface. The original planation surface may have continued as far as the more resistant folded limestone ridge southeast of the Pisuerga. The Ontañon ridge may have been a kind of low Inselberg on the planation surface, rising up at little height above it. In fact no boundary is present between the Quintanilla and Mataporquera surfaces. The *Mataporquera surface* is mainly developed in Keuper and Jurassic rocks, sharply bordered to the west by the Triassic. The same can be said of the *Espinosa surface,* but this partly extends on the Triassic rocks as well. To the east the Mataporquera surface is bordered by Cretaceous ridges over which passes the present Camesa-Ebro divide.

On comparison of the maps 1 and 2 it is evident that the *Redondo surface* is also bound to the softer rock sypes, and bordered by the resistant Palaeozoic rock types and by the Triassic.

From this brief summary it will be clear that the planation surfaces are generally associated with the less resistant rock types. This adjustment indicates that the planation process on the one hand originated from a fluviatile valley system which itself was adjusted to the softer rock types, that is a subsequent system, and on the other hand may be due to altiplanation, which could proceed rapidly in the less resistant rocks. The planation mechanism can thus be characterized as a combination of lateral planation by slope recession, and altiplanation. Lateral erosion may have produced broad valley floors, and slope recession, which proceeded easily in the soft rocks, must have started from these valleys.

We may suppose that the process, active at present in the Redondo region, is more or less similar to that which produced the planation surfaces, the remnants of which were described in the preceding paragraph.

Dating

From our description it may be seen that the individual parts we distinguished, have a genetic relationship and have developed partly in the zone between the "Pays Plissé" and the mountain chain, and partly within the chain, along the valleys. Their present heights vary from about 1200 m in the west to some 950 m in the east.

By the beginning of the deposition of the terrace gravel they must already have existed as more or less pronounced plains. That means that the planation processes must have worked since considerable time before the terrace sedimentation.

The characters of the HP, HR and HC terraces are strikingly identical: they are developed as plateau terraces of wide extension, covered with coarse pebble and cobble sediments the thickness of which is about 12—15 m, or 5—6 m on the Rubagón terraces and the most upstream parts of the Camesa terraces. From their character and from the sedimentary petrography it is evident that they have originated under equal climatic conditions and in the same period. The difference in height is easily understandable since they were formed as the valley floors of two fluviatile systems not in connection with each other, flowing at different levels.

On the other hand the planation surfaces except for the Redondo surface, were found to be parts of one and the same planation system, though the Mudá surface lay at a somewhat higher level than the rest of them. This again can be explained, considering that this Mudá surface had its base-level in a pre-Pisuerga river which flowed at a higher level than the pre-Camesa *). Altiplanation will not materially have altered this difference in height. There are no arguments for considering the Mudá surface as older than the other surface parts, also because the lack of a counterpart of such an older planation level in the Camesa-Rubagón area.

The planation, having originated from a subsequent valley system, may not be correlated with the pedimentation south of Guardo **).

If the pediment and the raña deposits are considered as formations of the same time, the planation in our region must be considered as younger than the time in which they were formed. If the pedimentation is considered as older than the raña deposition, and thus is looked upon as of Pliocene age, the planation in our region is at least younger than the pedimentation. Since no raña-like deposits were found in our region, not even below the high-terrace sediments, we may conclude that also when accepting the latter point of view, the planation must be younger than the raña time. So we may date the beginning of the planation somewhere in the Villafranchian, after the raña time, and before the beginning of the high-terrace sedimentation.

During the deposition of the terrace sediments on the valley floor, the planation must have gone on, providing still more room for the (braiding) rivers to deposit their sediments, and at many places the characteristic low-angled denudation slopes which gradually rise from the terrace level, were formed. These denudation slopes were mentioned several times in this paper.

During the rest of the Pleistocene and the Holocene the climatic changes may have caused changes in the slope formation regime, though it seems possible that the pre-Pleistocene shape is still visible; detailed investigations on the slope forms will be required before more can be said on this subject.

The Redondo surface is still being actively formed. It may stand apart from the other surfaces, but as has been said before, it equally may be of the same type and the same age as the other surfaces, the only difference being that it has not been dissected by fluviatile erosion. The second possibility, in our opinion, is the most probable.

*) Meaning the predecessors of the HP and HC rivers, respectively.

**) cf. pag. 378 where the points of view of MENSCHING (1958) and MABESOONE (1959) were summarized.

CHAPTER XII

MORPHOGENESIS

In this chapter we shall give an outline of the geomorphological development of the region discussed in the present paper.

Before the present relief originated, the Cantabrian Mountains went through a long structural, erosional and sedimentary history; some episodes of this history are revealed by the geology of the present chain.

After the Hercynian orogeny there remained a mountainous area supplying the sediments of the Permo-Triassic. In the present configuration the Triassic south of the main divide surrounds the Palaeozoic as a hemicycle in the east and the south but it may have extended farther westward on the Palaeozoic than it does now. During the remaining part of the Mesozoic, mainly clayey and calcareous sediments were deposited. The Meseta block, by then, was a planated Hercynian massive with a drainage towards the east. Its eastern coastline at times was situated near the present Iberic Mountains, but during the more important transgressions it shifted towards the west, so that some marine Mesozoic sediments were deposited on the eastern part of the Meseta. Farther to the West only continental Mesozoic deposits are found. According to Solé Sabaris (1952) the northern border of the Meseta block must always have been abrupt, transgressions coming from the North had only local importance.

The marine sequence of the Mesozoic was interrupted by the formation of the Wealden, depositing mainly fine-grained quartz conglomerates and sandstones, the material of which must have been derived from some remote source.

The epeirogene movements during the Mesozoic were slight and caused no important deformations; their effects were rapidly counteracted by erosion.

In the Tertiary the Alpine orogenic phases caused the borders of the Meseta block to be folded. Along the eastern border a thick Mesozoic sedimentary cover was folded in a saxonic type of folding (Solé Sabaris, 1952).

In the interior of the Meseta where the Mesozoic sedimentary cover was thinner or absent, the deformations mainly consisted of epeirogenic updoming and faulting accompanied by subsidence of the Castilian basins. The main folding and uplift of the borders of the Meseta occurred in the Savic phase; the influence of this phase on the development of the Meseta is extensively discussed by Solé Sabaris (1952).

The uplift caused strong erosion in the surrounding mountain ranges during the Miocene, and deposition of the debris in the Meseta basins. The Miocene sediments therefore are coarsest near the mountain borders, and become finer towards the centre of the basin, where they consist of clays, marls and evaporites. The Miocene sedimentation ended with the deposition of extensive layers of Pontian fresh-water limestone, the so-called Páramos limestone. The Principal Meseta Surface (Penillanura fundamental de la Meseta) must already have been formed before the Pontian, because the Paramos limestone reaches far into the beveled Iberic Mountains, where they are at present found at altitudes up to 1800 m.

South of our section of the Cantabrian Mountains two different conglomerates are found in the Tertiary sequence: a limestone conglomerate below and a quartzite conglomerate on top. The limestone conglomerate consists of Cretaceous limestone pebbles, which were found to have a nearby origin. They have been supplied from the North, so that we can conclude that in the time of the deposition of this limestone conglomerate, Mesozoic limestone was being eroded on the southern flank of this part of the Cantabrian Mountains. Whether farther back into the mountains the Palaeozoic was already exposed, remains uncertain. According to Mabesoone (1959) the lower part of the limestone conglomerate has steep dips whereas the younger conglomerate lies horizontal or nearly horizontal. The tilted conglomerate was, according to this author, deposited after the Pyrenean phase and tilted in the Savic phase together with the Mesozoic. After the Savic phase further limestone conglomerates were deposited, derived mainly from the desintegrating Palaeogene conglomerates.

Later, the supply of limestone ceased and was replaced by quartzite derived from Palaeozoic rocks, partly from Carboniferous quartzite conglomerates. This deposition went on through the Miocene but gradually the sediment type became finer-grained. This may point to a flattened relief though Mabesoone concludes from the foreland sediment analyses that a moderate relief still could have existed. Yet the planation process which caused the formation of the "Penillanura fundamental de la Meseta" will have affected the Cantabro-Asturian Mountains as well, because farther to the West, Birot and Solé Sabaris (1954) demonstrated the existence of a real peneplain. We assume that the peneplanisation also worked in our region and that the later uplift here has been greater than in the Galician region. As we remarked before, nothing of a planation level of this age has been left in our region, if it ever existed here.

After the Pontian, the Rhodanic orogenic phase caused the uplift of the Meseta block which at the same time was tilted towards the West. According to Solé Sabaris (1952) the amount of the uplift has been more than 3000 m at some places. This orogenic phase also caused a renewed uplift of the mountainous borders and of the Cordillera Central with respect to the Meseta basins, and it also caused some local tilting of Miocene deposits in front of the mountains. The tilting of the Meseta caused the drainage system to be directed towards the West instead of towards the East, as it was before. In this time the great Meseta rivers originated: the Duero north of the Cordillera Central, the Tajo south of it. Traces of the former eastward drainage direction of the Duero system can still be recognized at numerous places.

The Tertiary deformations visible in the part of the Cantabrian Mountains treated in this paper, were discussed by De Sitter (1957) and have already been mentioned in Chapter II. It seems that both the Savic and the Rhodanic phase performed these deformations.

The uplift of the whole of the Meseta block also created an important difference in altitude between the Cantabrian Mountains and the coastal region north of it. As was pointed out in Chapter I, the rivers flowing from the chain to the South are lying at a much higher level than those draining the northern half of the mountain chain. The latter started cutting back in southward direction after the uplift, capturing some upstream parts of the rivers flowing to the Meseta or towards the Ebro basin, often shifting the divide to the South. This process is still active (cf. Chapter I).

After the Rhodanic tectonical movements the planation started anew, forming a post-Pontian planation level. As was discussed in the preceding chapter, large-scale pedimentation occurred at many places in Spain, and also at the foot of the Cantabrian Mountains near Guardo; this pediment originally must have had a much greater extension, some traces of which were found by Mabesoone (1959). The raña debris are generally considered as having been formed contemporaneously with the pediments, though some authors think them to be younger than the pediments (Chapter II). A Villafranchian age is generally assumed for the rañas.

The planation surfaces observed in our region seem to be younger than the raña time though they are also considered as of Villafranchian age. As they have none of the characteristics of a pediment *), however, they must have originated in a different way, namely by lateral planation initiating from a subsequent valley system, accompanied by altiplanation, in a different climate which needs not have been arid.

This planation created an extensive intramontane and peri-montane basin in the southern part of the Cantabrian Mountains, mainly on poorly resistant rocks such as Keuper and Jurassic marls and Carboniferous shales. Various parts have been indicated by local names in map 1 (Mudá surface, Quintanilla surface, etc.).

The first direct indications of the presence of ancient rivers are found in the sediments of the HP, HC and HR terraces. At this time, two principal rivers existed: the *High Pisuerga* and the *High Camesa.*

The most important branch of the High Pisuerga came from the northwest; an affluent of it came down from the Triassic escarpment. In its upstream parts the High Pisuerga may have had a torrential regime, to become a braiding river as soon as it entered the Mudá surface where it deposited part of its load. It flowed southward through the Brezo gate, until it found the raña of Guardo on its way, which caused it to take a southeasterly course. Possibly the ancient river then flowed in the direction of Herrera, as was found by Mabesoone (1959). From there its course turned southward as it still is now. Within our region the sediments of the High Pisuerga were deposited over a large surface, and the thickness of the sediment layer is still over 12 m at present; its topographical height varies from 1140—1200 m. From the pebble analyses it could be demonstrated that most of the pebbles were supplied by the Carboniferous Curavacas conglomerate, which consists of already well-rounded quartzite pebbles. The climate under which the sedimentation took place was found to be free of glacial or periglacial influence; eolian actions also were unimportant. From the thickness and the wide lateral extension of the sediment may be assumed that the conditions of deposition were more or less constant during considerable times. The absence of ferruginous coatings on the pebbles is an additional argument for a temperate, rather warm and humid climate in the HP time.

The planation of the Mudá surface must still have been active at that time; though a flat topography must have existed already at the beginning of the HP sedimentation, the planation certainly has gone on during the HP time, and also after it.

The High Camesa flowed farther to the East, and at a lower level, viz.

*) In which the term pediment is restricted to land forms, originated under an arid or semi arid climate (cf. Chapter XI).

1000—960 m; it must also have been a braiding river. It had an important tributary in the High Rubagón. Together they covered an extensive plain with sediments, the thickness of which is in general from 10—12 metres, in the upstream parts still about 6 metres. An important portion of the sediment was provided by Triassic rocks, it consists of coarse pebbles mixed up with minor amounts of sand and clay. The sediment analyses show that it was deposited under the same climatic conditions as were the HP sediments in the Pisuerga area.

The HP, HR and HC terraces must be of equal age; no connection existed between the High Pisuerga on the one hand and the High Camesa-High Rubagón system on the other. The High Camesa passed through the Las Tuerces gate to the South, and most probably it discharged in the environs of Herrera into a river which may have been the High Pisuerga. This situation must have existed during the later Villafranchian, before the capture of the High Pisuerga.

Afterwards a westerly tributary of the High Camesa, having a subsequent direction in soft rocks, encroached upon the HP system by headward erosion, and finally the High Pisuerga was captured near Cervera. The Brezo gate became a dry gap and the river coarse was led eastward. The new valley floor, after an incision phase, became the present LH terrace. This capture must have taken place between the Villafranchian and the Riss glacial time, and most probably in the period between the Villafranchian and the Mindel time. As to the climate in the LH time, no certain conclusions could be drawn.

After the capture, the Pisuerga was directed towards the much lower level of the Camesa. This must have resulted in a local steepening of the gradient of the Pisuerga between Cervera and Aguilar. At present the LH terrace at Cervera lies at about 1080 m, in the San Mames region it is found at 1030 m, whereas the HC terrace in the environs of Aguilar lies at some 960 m. A counterpart of the LH terrace is absent downstream of the Humín hill, so that we cannot say at what level the Camesa lay in the LH time, whether at 960 m, or lower. Anyhow, the greatest steepening of the Pisuerga must have been situated between the Humín hill and the confluence with the Camesa.

The middle and Lower terraces of the rivers were deposited under periglacial climatic conditions. In these times large masses of screes were available, so that the rivers became overcharged which resulted in the formation of gravel deposits on the valley floors. The screes supply was largely determined by the absence of a protecting forest vegetation, and by downslope transport by solifluction.

In the interglacial times the rivers must have been less charged, and the valley floors were dissected so as to form terraces. This sequence was repeated several times. The Lower Terrace was found to date from the latest glacial, which may be correlated with the Würm glaciation. Because of the considerable height difference between the Lower Terrace and the lowest member of the middle terrace group, the latter is presumed to be of Riss age (LM and LMR terraces, respectively). The MM and MR terraces may represent an older glacial phase of the Riss time, whereas the position of the HM terrace is not yet quite clear. It may be older than Riss, that is presumably of Mindel age, but until a correlation with the terraces along the more downstream parts of the Pisuerga will be established, nothing certain can be said on the exact age of the HM terrace.

The absence of middle terraces of the Camesa has to be explained by assuming that they have been destroyed completely by lateral erosion of the Camesa, the valley being rather narrow. At present the river still wanders, meandering, from one slope of the valley to the other.

In the Rubagón area these intermediate terraces are again present (MR, LMR). Most probably, these terraces can be correlated with the middle terrace group of the Pisuerga, that is with the MM and LM terrace; the differences in topographical heights which exist between the Middle terraces of the Pisuerga and those of the Rubagón can be a result of the original height differences between the drainage basins of both rivers. Even nowadays the height differences between the Lower terraces at the points where the rivers leave the mountain chain, are considerable: the Pisuerga Lower Terrace at Cervera is at 1000 m, the Rubagón Lower Terrace at Cillamayor at 955 m and the Camesa at Mataporquera at 915 m. The Lower Terraces of all of the three rivers, nevertheless, were found to form a unit.

Glacial relief features were only formed in the summit region of the investigated area; they consist of a number of cirque basins and moraine walls. F. Hernandez Pacheco (1944) concluded to the occurrence of three glaciations, viz. Mindel, Riss and Würm. In our opinion at least the existence of Mindel deposits is doubtful. Farther westward, the glaciation(s) have been more important. In the upper Carrión valley, north and northeast of the Curavacas, many glacial cirques and important glacially deepened valleys are present, but this region falls outside our area.

Periglacial relief forms are found as relics of the last periglacial climatic stage, which must be of Würm age. Dry valleys (dellen) are widely distributed over the investigated area, and occur in two main types, the so called *hammock type,* and the *flat-floor type.* Many transitions from the latter to erosional brook valleys exist.

At some places the adjustment of the present drainage system to the new situation created by the capture of the High Pisuerga is clearly demonstrated. A typical situation is found east of Herreruela. Here the Rio Castillería flows to the West at a height of 1300 m. On its southern bank a pass lies at some 25 metres above the level of the river, whereas south of that pass the valley of a brook runs southward with a very steep gradient, much steeper than that of the R. Castillería. After a course of only 9 km the brook lets out into the Pisuerga at Rueda, at a point which, measured along the course of the Pisuerga, is about 25—30 kilometres downstream of the pass. It is clear that a capture will take place here, geologically speaking, in the "near" future, thus shortening the course of the water from the origin of the Castillería river with more than 16 kilometres. Before the capture of the High Pisuerga, a westward direction towards the Brezo gate was the shortest. Now, after the capture, it is a detour, and there is a tendency to shorten the course.

Another remarkable situation which was mentioned already in Chapter I, exists at Quintanilla, where geologically speaking, the whole upstream parts of the Camesa and of the Rubagón will soon be captured by the Arroyo Mardancho, a tributary of the Ebro. This will result in a considerable increase of the Ebro drainage area; the main divide between the Duero and Ebro areas will then run from the hills south of Quintanilla to the West along the Ontañon ridge, and from there along the present divide between the Rubagón and Pisuerga areas to the Valdecebollas region. The curious course of the present divide between the Ebro and Camesa systems may be due to similar capture processes in former stages.

Earlier in this paper we mentioned the attack by headward erosion from the northern flank of the Cantabrian Mountains. A very complicated situation may be expected when the whole upstream part of the Ebro is captured by the Rio Besaya.

The important changes in drainage pattern which we traced in the geological past are, indeed, not the last to occur. If Nature would be given a free hand, equally great changes are about to occur.

APPENDIX

PRELIMINARY REMARKS ON CLAY MINERAL COMPOSITIONS

A few samples have been analyzed on clay minerals, in order to get a preliminary impression of their clay mineral composition. The X-ray diagrams were prepared by Mr. A. Verhoorn by means of a Guinier camera; the diagram interpretations were made by Mr. Th. Levelt. The probable error may lie within some 10 % of the figures given in table 17.

TABLE 17.

Mineral compositions of some clay fractions. Anal. Th. Levelt.

No.	Terraces	Montmorillonite	Illite	Kaolinite	Quartz	Goethite	Magnetite
117	Pisuerga Lower Terrace, Salinas	tr.	70	20	8—10	tr.	—
210	Dam Aguilar	—	75	20	5	tr.	—
8	Pisuerga, MM, Barcenilla	5—10	65	25	2—3	5	5
60	Pisuerga, HP, Dehesa ...	—	75—80	10	2—3	10	—
206	Rubagón, HR, Cillamayor	—	60—65	25—30	2—3	10	—
115	Camesa, HC, Menaza	—	65	25	8—10	tr.	—
	Sand layers						
49	Cervera, boring 1	5—10	45	35	2	10	—
58	Cervera, below HP terr. .	tr.	50	40	tr.	10	—
213	Mataporquera, below HC terr.	—	60	30—35	tr.	5	—
120	Cuena terrace	—	70	25	2—3	2—3	—
121	Cuena terrace	—	65	30—35	3—5	tr.	—
	Weathering clays						
101	Wealden clay, Matamorisca	—	60	35—40	3.5	tr.	—
19	Westphalian shales, Mudá	—	85	10	5	—	—
2	Devonian limestone, Peñas Negras	—	+	+	+	tr.	—

The following remarks can be made on the results.

Terraces. No differences between the lower, middle and higher terraces seem to exist as for their clay mineral compositions. Neither are there differences between the HP, HR and HC terrace sediments. Montmorillonite is absent or very insignificant; illite on the contrary is the most frequently occurring clay mineral in all the terrace samples analyzed, its percentage ranging from 65 to 80. The kaolinite content varies, in general, between 20 and 30 %, only one sample showing a lower percentage.

Beside clay minerals, quartz and goethite occur in minor amounts, whereas a magnetite content of 5 % was found on the MM terrace. The latter may have some importance as it demonstrates that magnetite can occur in the size fraction < 1 micron.

The sandy sediments below the HP terrace at Cervera, and below the HC terrace at Mataporquera (samples 49, 58 and 213 respectively) differ from the terrace sediments in that they have a somewhat higher kaolinite content, viz. 30—40 %, whereas the illite content is correspondingly lower, viz. 45—60 %. Montmorillonite, quartz and goethite play a subordinate part. The clay from the sand layers at Cuena (samples 120 and 121) has a somewhat higher illite content, with a kaolinite percentage ranging between 25 and 35.

The weathering-clays also have high and dominating illite contents. The weathering-clay from the Devonian limestones of the Peñas Negras could only be analyzed qualitatively. Montmorillonite was found to be absent in these samples, whereas kaolinite is always present, in percentages between 10 and 40.

From the analyses it is evident that the clay mineral composition of the sediments has been inherited from the source rock. The conditions during the weathering do not seem to have altered the clay mineral composition of the source rocks in a considerable way, and neither did the conditions during or after the deposition. Besides, the conditions during the deposition will not have been very different from those during weathering in the source area, both areas being not more than at most 60—70 km apart.

In our opinion, no conclusions on the climatic conditions during or after the deposition of the sediments can be drawn from these analyses, and the same applies for the climate during weathering in the source area. Only the higher kaolinite content of the sandy layers below the HP and HC terraces seems to point to a climate different from that of the High terraces time.

The high illite content of the other samples is easily understood as the greater part of the clay fractions will have been supplied by Palaeozoic shales; this also explains the insignificance of montmorillonite (Grim, 1953, although later investigations showed that montmorillonite is not always absent in Palaeozoic sediments).

SUMARIO

Capítulo 1. Introducción

Se han ejecutado investigaciones geomorfológicas en la parte meridional de la Cordillera Cantábrica (dib. 1), en el terreno drenado por el tramo superior del Río Pisuerga, por el Río Camesa, afluente del mismo, y por el Río Rubagón, afluente del Río Camesa. Se encuentra la región investigada en la zona donde se halla el límite entre las rocas Paleozoicas y las Mesozoicas de la Cordillera (mapa 2). Más hacia el Sureste, desde Cervera de Pisuerga se extiende una zona de rocas Mesozoicas plegadas, llamada por Ciry (1939): "Le Pays Plissé" (mapa 1). Es una zona de relieve intermedio, ni tan alto como la Cordillera Cantábrica, ni tan llano como la Meseta, que se encuentra más hacia el Sur de dicha zona.

Existe una gran diferencia geomorfológica entre las vertientes septentrional y meridional de la Cordillera Cantábrica, como resultado de la situación alta de la Meseta. Los ríos de la vertiente norte en una recorrida de cerca de 50 kilómetros llegan el Mar Cantábrico y así pasan un desnivel de más de 1300 metros; los ríos de la vertiente sur se dirigen a la Meseta que aquí, en su parte norte, tiene una altura de 1000 metros. Es decir, poco más o menos, en la misma recorrida, los ríos pasan un desnivel que es 1000 metros menor que el de los ríos de la vertiente norte. Como resultado, los valles de la parte norte están profundamente agrietados, con considerables pendientes, caracterizándose la parte sur por amplios valles, con suaves pendientes; es la misma altura topográfica, pero el fondo de los valles se encuentra a unos 1000 metros más alto que en la parte norte (dib. 2).

Menos pronunciado, pero también claramente visible es el contraste en relieve con la región de la cuenca del Río Ebro, que limita la cuenca del Camesa en el norte y noreste.

El clima de la región considerada forma la transición entre el clima de tipo atlántico de la costa cantábrica, y el clima semi-árido del interior de la Meseta. En dib. 3, el clima de Cervera de Pisuerga y de Reinosa está ilustrado gráficamente (según F. Hernández Pacheco, 1944).

La cartografía de las unidades morfológicas ha sido realizada a base del Mapa de España, escala 1:50.000. Las hojas utilizadas se presentan en dib. 1. La naturaleza litológica de los cantos de terrazas fluviales fué determinada en los cantos mayores de 2 cms de diámetro; el índice de desgaste fué determinado en los cantos mayores de 4 cms de diámetro. Es para eliminar la influencia de las pudingas triásicas que no hemos considerado los menores de 4 cms (veáse Capítulo 3).

Se calcula el desgaste mediante la fórmula de Cailleux:

$$Ie = \frac{2\,r^{e} \cdot 1000}{L}.$$

La granulometría de arenas y arcillos fué realizada por el método de "criba-pipeta"; los resultados son representados por curvas logarítmico-cumulativas.

El desgaste de los granos de cuarzo se obtuvo de la misma manera que el desgaste de los cantos rodados; el examen de las muestras se ejecutó bajo el micróscopo binocular.

La determinación de los minerales densos se hizo de la manera acostumbrada.

Capítulo 2: Geología

Las más importantes características geológicas de la región investigada se describen en este capítulo, según las investigaciones de los autores Karrenberg (1934), Ciry (1939), Quiring (1939), De Sitter (1955 y 1957) y Kanis (1956).

Rocas cristalinas apenas si se encuentran. El Devónico se halla en la parte NO de la cuenca del Río Pisuerga y se compone de areniscas cuarcitosas y cuarcita, alternando con calizas. En el Carbonífero tres unidades litológicas pueden distinguirse: calizas masivas y cristalinas, conglomerados de gran espesor (el llamado conglomerado Curavacas) y una alternación de pizarras, areniscas y conglomerados, a veces también de calizas. Se compone el Permo-Triásico de conglomerados más finos y claramente distintos de los Carboníferos, y de areniscas gruesas, de color rojizo. El Keuper principalmente se compone de margas y arcillas; el Jurásico de calizas bien estratificadas y de margas. El Wealden tiene una litología muy característica, componiéndose de conglomerados finos de cuarzo y cuarcitas, calizas lacustrinas, y areniscas bastante gruesas. Está mal cementado, de modo que por la alteración se forman fácilmente arenas y cascajos. El Cretaceico superior sólo se encuentra en unos lugares, como al Sur de Cervera de Pisuerga. Se compone, generalmente, de calizas.

Las estructuras de la fase Sudética (llamada la fase Curavacas por De Sitter) tienen una dirección E—O, las de la fase Asturiana (fase Peña Cilda) una dirección NNO—SSE. Las deformaciones Terciarias son visibles en la región del Valdecebollas, pero quedan sin datar.

Capítulo 3: Alteración, denudación y formación de pendientes en diversos tipos de rocas

La Caliza de Montaña forma el relieve en toda la Sierra del Brezo. En ningún lugar hemos hallado sedimentos con derrubios derivados de esta Caliza, salvo en una brecha situada al pie de su vertiente meridional. Las pendientes de denudación ("Richter-slopes", cotéjese Bakker, 1952) de esta Caliza son muy características, con ángulos de inclinación de 25—30° (dib. 5). Otras calizas Paleozoicas, por encontrarse más aisladas, tienen menos importancia en relación con la formación o deformación de pendientes.

En el conglomerado Curavacas, que se encuentra en una región extendida, las pendientes de denudación pueden tener los ángulos más variados, pero las transiciones son siempre suaves. Los conglomerados Triásicos son más finos y más compactos, de suerte que reaccionan de manera completamente diferente en la eflorescencia. En el conglomerado Curavacas la "matriz" de los cantos se pulveriza, de manera que los cantos individuales son librados, los conglomerados Triásicos, al contrario, reaccionan a lo largo de diaclasas, de tal manera que se forman cantos compuestos de conglomerado Triásico.

Las pendientes de denudación en las rocas Triásicas son de perfil sencillo, rectilinear o suavemente curvado (dib. 5).

Las esquistas Paleozoicas no tienen gran resistencia contra la alteración; rápidamente se descomponen en arcillas, pero por la fuerte erosión generalmente desaparece la arcilla formada, dejando la roca expuesta a nueva alteración. Por eso, la mayoría de las pendientes de esquistas es muy compleja, no existe un tipo general. Las areniscas forman en muchos sitios interrupciones de las pendientes, a causa de su mayor resistencia. La composición de los minerales densos de unos productos de alteración se presenta en dib. 7.

Capítulo 4: Fenómenos glaciarios y periglaciarios

Los fenómenos glaciarios de la región investigada han sido estudiados ampliamente por F. Hernández Pacheco (1944), junto con los del valle de Campo de Suso. Por eso, no nos hemos ocupado intensivamente de tales fenómenos.

Fenómenos periglaciarios se observan en toda la región. Hay bloques de dimensiones impresionantes (dib. 10), que se han deslizado suavemente hacia abajo sobre un suelo permanentemente helado, bloques que se encuentran, sobre todo, en las regiones más elevadas. Luego hay "dellen", valles secos de perfil transversal de forma concava (Schmitthenner, 1925), entre los cuales pueden distinguirse dos tipos: el tipo "hamaca" y el tipo de "suelo llano" (dibs 11 y 12, respectivamente). El suelo de estos últimos es más llano que el de los primeros, pero también concavo. Finalmente, la soliflucción ha sido muy activa en toda la comarca. Es difícil observar, dónde sólo ha sido activa bajo el clima periglaciario, y dónde todavía sigue activa como "soil creep", el que hemos encontrado en muchos sitios.

Capítulo 5: Descripción de las terrazas del Río Pisuerga

El Río Pisuerga se caracteriza por la presencia de numerosos restos de terrazas fluviales. Pueden agruparse en los niveles siguientes:

La	terraza	HP	altura	relativa	120—150 m
"	"	LH	"	"	80—100 "
"	"	HM	"	"	50—55 "
"	"	MM	"	"	cerca de 40 "
"	"	LM	"	"	20—30 "
"	"	HL	"	"	5—10 "
"	"	Baja	"	"	hasta 5 "

Dibujo 13 representa un perfil longitudinal del Río Pisuerga, con la proyección de las terrazas. El número de cada una de las partes individuales corresponde con el número de la descripción en Capítulo 5.

Terraza HP. Las partes de Herreruela (1) y San Felices (2) son casi libres de sedimentos. Al NO del Pantano de Vañes se encuentran las partes de Polentinos (3) que están cubiertas de un mezclado de cantos cuarcitosos, Triásicos y areniscos. Al NO de Cervera de Pisuerga se encuentra la parte de Cervera (5) (dibs. 14 y 15), formada de una llanura alta, de dimensiones impresionantes, cubierta de una capa de gravas fluviales, principalmente cuarcitosas, de un espesor de 12—14 metros. Al otro lado del valle del Pisuerga se halla la parte de Rabanal (6) que resulta la continuación de la parte de la Cervera. Al Sur del valle del Río Rivera se hallan las partes de Vado y de Dehesa (7) (dib. 16), que claramente son del mismo nivel. La altura relativa es la misma que la de la parte de Cervera, igualmente existe la cobertura sedimentaria de cantos cuarcitosos, encontrándose en ella cantos del conglomerado Triásico en una proporción de menos de 1 %. Es importante esta presencia, porque indica que anteriormente el llamado Pisuerga Alto (el río tal como existía en la época de sedimentación de la terraza HP) desde Cervera continuaba en dirección sur, pasando por el Puerto del Brezo, que es la depresión marcada entre las rocas Mesozoicas del Mariserrana, y las calizas Carboníferas de la Sierra del Brezo. Más hacia el Sur se ensancha la terraza y queda menos claramente visible. Esta parte ha sido estudiada por Mabesoone (1959).

La terraza LH sólo se halla cerca de Cervera (4), a una altura relativa de 80—100 metros; se caracteriza por la ausencia de cantos, estando la superficie formada en un sedimento arenisco que también se encuentra bajo la terraza HP. Parece que este sedimento es de más edad que la terraza HP. Cerca de Ligüerzana, se halla una parte de la terraza LH a una altura de cerca de 80 metros sobre el nivel del río; aquí los cantos cuarcitosos tienen un espesor de cerca de 2 metros. Al Sureste de Salinas, se hallan restos de la terraza LH en las partes de Barrio (13) y de Humín (15). En las dos, los cantos son escasos; sin embargo, la cobertura sedimentaria alcanza un espesor de 3—4 metros.

Las terrazas intermedias. El nivel HM se encuentra en las partes de San Mames (14) y de Frontada (16). Hay una cobertura de sedimentos fluviales, de un espesor de 2 a 3 metros. El nivel MM se halla en las partes de Barcenilla (11) y Salinas (12). Aquí también el sedimento tiene un espesor de 2—3 metros. El nivel MM se ha conservado en sitios aislados (8, 9, 17).

La terraza Baja. El nivel HL sólo se encuentra al NE de Aguilar; la terraza propiamente dicha se presenta casi en todas las partes del tramo del Río Pisuerga, salvo en el tramo superior (cotéjese mapa 1).

Capítulo 6: Petrografía sedimentaria de las terrazas del Río Pisuerga

El estudio de los sedimentos fluviales conduce a las conclusiones siguientes. Los cantos de todas las terrazas de cualquier altura relativa se componen en su mayoría de cuarcitas, procedentes del conglomerado Curavacas. Los cantos de la terraza HP se caracterizan por índices de desgaste bastante altos, que excluyen una influencia de clima periglaciario en la época del Pisuerga Alto. Los cantos de las terrazas intermedias y bajas están mucho menos rodados, lo que indica la influencia del clima periglaciario en aquellos tiempos. El análisis de los sedimentos nos demuestra que el sedimento ha sido depositado bajo condiciones de "braiding rivers", es decir que hubo más derrubios de los que el río pudo transportar.

Los depósitos de las terrazas intermedias también han sido sedimentados bajo importantes alternaciones en el régimen fluvial. Como son menos espesos y tampoco tienen la gran distribución horizontal de los sedimentos de HP, las épocas en las cuales fueron depositados habrán sido bastante más breves.

Los granos de cuarzo de 500—1050 μ de diámetro son generalmente angulares, como se ve del dib. 27. Unos porcientos tienen altos índices de desgaste, lo que puede indicar que localmente ha habido influencia eólica.

Los análisis de los minerales densos se presentan en el cuadro 10 y en el dib. 28, en los cuales se observa una predominancia de los minerales circón, turmalina y rútilo. La estaurolita procede del Triásico, pero esto no quiere decir que todo el Triásico se caracterice por la presencia de estaurolita.

De las observaciones hechas se concluye que en la época del Pisuerga Alto, el río tenía dos importantes arterias superiores, una de ellas procedente de la zona del conglomerado Curavacas, bajando la otra del escarpamiento del Triásico. Desde Cervera continuaba al Sur, pasando por el Puerto del Brezo. De la continuación de la terraza HP con respecto a la raña de Guardo, se deduce que la terraza es más reciente, es decir que probablemente es de edad Villafranquiense superior. Después, el Pisuerga Alto fué capturado por un afluente del Camesa Alto, que en un tramo subsecuente en rocas de poca resistencia podía agrietarse rápidamente por erosión regresiva. Después de la captura, el Río Pisuerga se desvió desde Cervera hacia el Este; el nuevo suelo del valle, tras una fase de incisión, formó la terraza LH.

Las terrazas intermedias (HM, MM y LM) fueron depositadas bajo un clima periglaciario; los niveles MM y LM se atribuyen a la glaciación Rissiense, no siendo segura aún la edad del nivel HM. La terraza baja, además del carácter periglaciario de sus sedimentos, se caracteriza por la desembocadura de diversos "dellen", que también ofrece un argumento para atribuir su origen a la glaciación Würmiense.

Capítulo 7: Descripción de las terrazas del Río Rubagón

Existen diferencias considerables entre el Pisuerga y el Rubagón: la cuenca de éste es mucho menos extensa; las terrazas fluviales son, por consiguiente, menos grandes y se encuentran, además, en niveles más bajos, tanto en sentido relativo como absoluto. Pueden distinguirse cuatro niveles:

La	terraza	HR	Altura	relativa	55—70 m
,,	,,	MR	,,	,,	40—50 ,,
,,	,,	LMR	,,	,,	15—20 ,,
,,	,,	Baja	,,	,,	0— 5 ,,

Están representadas en dib. 29, con el perfil longitudinal del Río Rubagón hasta su desembocadura en el Río Camesa. Los números de las terrazas en el texto corresponden con los en el perfil.

La terraza HR se halla en las partes 4, 6 y 7. El espesor de la cobertura sedimentaria varía de unos 2 metros a seis o siete metros. Se compone el depósito fluvial de cantos de conglomerado y de arenisca gruesa Triásicos y cantos cuarcitosos; el diámetro de los mayores cantos excede los 70 cms.

Aquí, lo mismo que en la cuenca del Pisuerga, se observan en muchos sitios pendientes de denudación con ángulos pequeños que se levantan suavemente sobre el nivel de la terraza alta.

Más hacia el Sur en la comarca de Matalbaniega y Nestar, se presentan tres restos de una terraza alta, con alturas de 1000—980 metros. Como veremos más adelante, forman parte de la terraza alta del Camesa.

La terraza MR se halla en las partes 3, 8, y probablemente, 1. Salvo éste último, estas partes están cubiertas de una capa sedimentaria de cantos, de un espesor de 2—3 metros. La terraza LMR se encuentra en las partes 2 y 9. También están cubiertas de una cobertura de cantos.

La Terraza Baja se extiende desde Barruelo de Santullán río abajo, y localmente alcanza una anchura de más de 500 metros. La cobertura de cantos tiene un espesor de unos 2—4 metros.

Capítulo 8: Petrografía sedimentaria de las terrazas del Río Rubagón

La naturaleza litológica de los cantos está representada gráficamente en dib. 33, en el cual se ve que domina la cuarcita, mezclándose con los cantos del Triásico. Los índices de desgaste se dan en el dib. 34. Por la ausencia de conglomerados espesos que suministren cantos cuarcitosos ya rodados, son distintos los diagramas de dibs. 21 y 34. Sin embargo, puede concluirse que los cantos del sedimento HR demuestran un transporte fluvial de corta distancia, en el cual no hubo influenca glaciaria ni periglaciaria. La terraza LMR, al contrario, claramente indica una influencia periglaciaria. En la Terraza Baja también puede ser observada una influencia periglaciaria, pero ha sido menos importante que en el caso LMR.

La granulometría de las muestras indica deposición bajo un régimen fluvial con grandes variaciones de caudalosidad. Véase dib. 35. El contenido algo mayor de la fracción "silt" (2—50 micrón) en las terrazas LMR y Baja puede atribuirse a la acción del viento.

Los granos de cuarzo son generalmente angulares (dib. 36), con una excepción importante: la terraza MR, cuyo sedimento está bien rodado y como tal refleja el carácter periglaciario de su cobertura sedimentaria.

Los minerales densos (dib. 37, cuadro 13) enseñan la predominancia de los minerales turmalina, circón y rútilo. El contenido de topacio de una parte de la terraza Baja fué causado por acarreo desde el Oeste, de la région Wealdense.

Capítulo 9: Descripción de las terrazas del Río Camesa

Sólo hay dos niveles de terrazas del Camesa: la terraza HC, de altura relativa media de 60—75 metros, y la terraza baja.

La terraza HC se halla, extendiéndose desde Mataporquera (dib. 38), en las partes 2, 4 y 5, con una afluente en el valle del Arroyo de la Canal (3), y en las partes de Matalbaniega. Está cubierta esta terraza de un sedimento de unos 10—12 metros de espesor; sólo en las partes superiores (Mataporquera y Arroyo de la Canal) no alcanza más de 6—8 metros.

No hay terrazas intermedias.

La Terraza Baja del Río Camesa es distinta de las de los Ríos Pisuerga y Rubagón, por no tener cantos en su superficie. Por el perfil longitudinal de la pendiente extremadamente baja, la potencia de erosión y transporte es casi nula. Los cantos, si los hay, se pierden en los depósitos turbosos del agua estancada.

Capítulo 10: Petrografía sedimentaria de las terrazas del Río Camesa

Por ausencia de afloramientos, no hemos podido tomar muestras de la Terraza Baja, y tampoco fué posible realizar análisis de los cantos. Así es que sólo se puede observar que los sedimentos de la Terraza Baja deben reflejar las características de la terraza HC, porque ésta se encuentra casi en todos los sitios sobre la terraza baja, en la ribera derecha. Los numerosos meandros indican que, si han estado presentes anteriormente, los restos de terrazas intermedias pueden haber desaparecido fácilmente por la erosión lateral de este valle bastante angosto.

Así es que sólo hemos podido estudiar los depósitos de la terraza HC. En dib. 44 se presenta la naturaleza litológica de los cantos, de la cual se ve claramente la importancia de los cantos compuestos del Triásico. La influencia del Río Rubagón en este sedimento se manifiesta en un aumento del porcentaje de cantos cuarcitosos. Los cantos cuarcitosos que han sido encontrados en el valle del Arroyo de la Canal, en cambio, deben ser procedentes de bancos de conglomerado grueso cuarcitoso, que seguramente están presentes en el Triásico.

En la dirección río abajo, observamos un aumento de desgaste de los cantos (dib. 45). Influencias periglaciarias resultan ausentes. De los análisis granulométricos (dib. 46A) se ve que la fracción de diámetro $<$ 2000 micrones es bastante homógena. Los bancos arenosos bajo los cantos de la terraza también son de origen fluvial, y pueden ser más antiguos que la terraza HC.

El desgaste de granos de cuarzo de 500—1050 micrones de diámetro está representado gráficamente en dib. 47. Son angulares, con muy pocas excepciones. Los minerales densos se han puesto en el cuadro 16.

Son muy similares los caracteres fisiográficos de las terrazas HC del Camesa y de HP del Pisuerga. Por ejemplo, el espesor de las coberturas sedimentarias es casi igual en ambos casos; además, las dos terrazas se han desarrollado igualmente como "terrazas de plataforma", y, salvo la naturaleza litológica de los cantos, son muy semejantes los caracteres petrografíco-sedimentarios. La terraza HR del Rubagón desemboca en la terraza HC, de tal manera que el "Rubagón Alto" debe haber sido un afluente del "Camesa Alto". Llenaban los ríos juntos parte de la llanura, situada entre la Cordillera Cantábrica y el "Pays Plissé" (cotéjese Cap. 11).

Capítulo 11: Superficies de planación

Prerrodánico. Tras los movimientos tectónicos de la fase sávica en el centro de la Meseta y en las cordilleras marginales, se desarrolló la "Penillanura fundamental de la Meseta", bien conocida de publicaciones de diversos autores, y discutida ampliamente por Solé Sabaris (1952). Ya antes del Pontiense existía esta penillanura, que se extendía ampliamente y que fué levantada y basculada por la fase rodánica. En Galicia, también han sido encontrados restos de la penillanura fundamental de la meseta, y según Stickel (1930) también estarían presentes en numerosos sitios en la Cordillera Cantábrica, por ejemplo en las comarcas del Puerto de Piedras Luengas. Nosotros, sin embargo, no hemos observado ninguna indicación de tal penillanura en este sitio. Puede ser que se encuentre más al Oeste, pero en la región investigada por nosotros, seguramente falta en la actualidad.

Postrodánico. Después de los movimientos rodánicos, la erosión formó otra vez amplias superficies de planación, bajo un clima árido o semi-árido; son pedimentos, claramente visibles en muchas partes de España. Al Sur de la Cordillera Cantábrica, se desarrolló un pedimento del cual se reconocen ahora los restos al Sur de la villa de Guardo. Sobre los pedimentos se hallan coberturas de derrubios, generalmente cantos angulares o mal rodados, las rañas. Hasta ahora las rañas y los pedimentos fueron considerados como siendo de la misma edad, pero recientemente, Mensching (1958) pronunció la posibilidad de que los pedimentos fuesen de más edad, e.d. del Pliocénico, que las rañas, que tienen edad Villafranquiense.

Al Sur de la Sierra del Brezo se presenta un fénomeno similar: existe una llanura, cubierta de una brecha calcárea. Es el único sitio donde se hallan sedimentos con derrubios de la Caliza de Montaña en la región que hemos investigado. Probablemente, esta llanura es de la misma edad y del mismo origen que las rañas, es decir de la época Villafranquiense.

En nuestra región, existen numerosos restos de superficies de planación que, sin embargo, no tienen carácter de pedimento y sobre los cuales tampoco se hallan derrubios angulares.

Hay más razones para no considerarlas como pedimentos. Están claramente relacionadas con las rocas de poca resistencia, y, por tanto, la planación debe haber originado de los valles de un sistema fluvial subsecuente. Pero como son más antiguas que las terrazas altas, también deben ser de edad Villafranquiense.

Todos los restos de superficies de planación son evidentemente partes de una superficie, o puede decirse que todas las partes son de la misma edad. La superficie está situada más alto en la llamada superficie de Mudá (véase mapa 1: A), bajando hacia el Sureste. Para facilitar la descripción, hemos indicado las partes individuales con nombres de pueblos situados en estas partes. Sólo el nivel de Redondo parece formarse activamente hasta ahora; puede ser que originalmente fuera de la misma edad que las otras, pero ahora existe una diferencia con éstas, que son fósiles.

Capítulo 12: Morfogénesis

Después de las fases orogénicas hercínicas, la Cordillera Cantábrica ha tenido una historia muy compleja. Los efectos de las orógenas terciarias se muestran en la plegadura de los sedimentos Mesozoicos marginales alrededor del bloque meseteño, y en los movimientos epirogénicos del mismo. Así se formaron las depresiones castellanas y la Cordillera Central (Solé Sabaris, 1952). El Terciario al Sur de la région investigada se presenta como dos series de conglomerados: una de cantos de calizas Cretaceicas, de edad probablemente Eocena u Oligocena, y otra de cantos cuarcitosos de edad Miocena. Según Mabesoone (1959), el conglomerado inferior, de cantos calicíferos, fué depositado después de la fase pirenaica, y plegado en la fase sávica. Después de esta fase, continuó inicialmente la entrega de cantos de caliza, que posteriormente fueron sustituídos por cantos cuarcitosos. Después, el tipo de sedimentos fué haciéndose más fino. Pero de esto no puede concluirse que existiera un relieve llano en la Cordillera Cantábrica.

Tras la fase rodánica, que causó el levantamiento del bloque meseteño y su basculación, por la que se formaron las grandes arterias fluviales de la meseta que se dirigían hacia occidente, se inició en muchas partes de España la pedimentación, como ya hemos indicado en el capítulo precedente. En nuestra región, la planación tenía otro tipo, pero también es de edad Villafranquiense. En el Villafranquiense superior, el régimen fluvial cambió de tal manera que los ríos tuvieron el carácter de "braiding rivers", que depositaban importantes masas de cantos en las llanuras intramontanas, que ya existían como resultado de la planación. Había, en aquella época, el sistema del Pisuerga Alto, y el del Camesa Alto, del cual el sistema del Rubagón Alto era un importante afluente. No existía una conexión entre los dos sistemas. Posteriormente, el Pisuerga Alto fué capturado por un afluente del sistema del Camesa Alto, que tenía gran potencia erosiva, por pasar, en un tramo subsecuente, por rocas de poca resistencia. Luego, en tiempos de clima glaciario o periglaciario, se depositaron las terrazas intermedias y bajas. La terraza baja es de edad Würmiense, los niveles LM/LMR y MM/MR son de edad Rissiense, no siendo segura aún la edad del nivel HM, e.d. o de Rissiense antiguo, o Mindeliense. Las formas de relieve glaciares, en esta región, no tienen gran importancia, las periglaciares son los bloques, los "dellen", que se hallan en dos tipos, y la solifluccíón.

Hablando geológicamente, en el futuro próximo, una captura del sistema Rubagón/Camesa superior por el Arroyo Mardancho, afluente del Ebro, tendrá lugar en Quintanilla de las Torres. Se predice, asimismo, una captura del tramo superior del Ebro por el Río Besaya cerca de Reinosa.

Así le quedará claro al lector, que las modificaciones de sistema fluvial que hemos establecido en el pasado, no serán las últimas; en el futuro geológico, si la naturaleza puede actuar libremente, se producirán modificaciones igualmente importantes.

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