TERTIARY AND QUATERNARY SEDIMENTATION IN A PART OF THE DUERO BASIN PALENCIA, (Spain)

BY

J. M. MABESOONE

CONTENTS

PREFACE

INTRODUCTION

The Tertiary sedimentary basins of the Spanish highland plateaus are well suited for sedimentological work, especially for establishing the relations between the sediments and the source areas in the surrounding mountain ranges. This kind of work only recently started in Spain, and hitherto has been limited to the western part of the Ebro basin and to some other basins in that region.

The Sedimentological Section of the Geological and Mineralogical Institute of the Leiden University, under direction of Prof. Dr A. J. Pannekoek, selected a part of the Duero basin for this purpose. It adjoins the Cantabrian Mountain chain, where geological work is being done by Prof. Dr L. U. de Sitter and his collaborators of the same institute. In the area chosen we could expect to obtain from sedimentological work some information on the depositional environment, and also on the evolution of the Cantabrian Mountains, along the lines expressed in Cadisch' well-known paper: "Das Werden der Alpen im Spiegel der Vorlandsedimentation" (1928).

During the summers 1956—1958 a region south of these mountains, between the rivers Pisuerga and Carrión, up to their confluence near Venta de Baños, was investigated. The sediments were described according to their field characteristics, and some 600 samples were collected for laboratory analysis. In the field the analyses of the coarse sediments were carried out, in particular the pebble analyses of the conglomerates and of the terrace deposits.

The laboratory work was executed in the recently founded sedimentological laboratory of the Geological Institute at Leiden. It consisted mainly of grain size analyses, preparing of the heavy mineral slides, and chemical investigations. X-ray analyses of clay minerals have been done by the Mineralogical and Petrological Section of the same institute.

The absence of earlier studies on the same subject, and therefore the great extent of the investigated area, required that no more than the main features could be investigated. Detailed studies on separate layers, on their extension and differentiation, could not be made. Based on the data obtained by the sedimentological work, a reconstitution of the basin sedimentation was attempted, as influenced by the environments of deposition and by the bordering mountain chain.

The following sheets of the topographical maps on the scale 1:50 000, published by the "Instituto Geográfico y Catastral", have been used: 132, 133, 164, 165, 197, 198, 235, 236, 273, 274, 311, and 312. Of the geological maps on the scale of 1:50 000 the sheets 133, 235, and 273 are the only published up to now on the investigated area. The area also occurs on the geological maps on the scale 1:400 000, sheets 11 and 12.

For the principles on which our sedimentological work was based we may refer to the standard works of Cailleux (1956), Dunbar & Rodgers (1957), Milner (1952), Pettijohn (1957), and Preobraženskij & Sarkisjan (1954).

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CHAPTER I

SOME GEOGRAPHICAL REMARKS

1. DUERO BASIN

Physiographical and geological descriptions of the Duero basin have been published by Ed. Hernández-Pacheco (1915, 1934), Royo Gómez (1922), and Solé Sabarís (1952). Based on these authors, and on our own observations, a short description of the whole region will be given.

The Duero basin forms the northern half of the Spanish Meseta, which is divided into two parts by the Cordillera Central. It is a great plateau, sloping to the W, including nearly the whole of Old-Castile and León, and drained by the river Duero and its principal affluents. The lowest point is found at 630 m in the valley of the Duero near Zamora. Towards the borders and the E it rises to over 1000 m. The mean height is between 850 and 900 m.

This plateau, the surface of which consists of Tertiary and younger sediments, is surrounded by a number of high mountain chains, except in the SW. The Cordillera Cantabrica, rising steeply from the flat plateau, forms the northern border. In the north-western part are found the mountains of León and the Sierras de la Peña and de la Culebra, consisting of Palaeozoic rocks. Towards the SW the boundary is formed by the heights of Almeida and the Serra de Marofa on Portuguese territory. In the region near Salamanca the border is only little higher than the plateau more inland.

The southern borders are less conspicuous. Only small mountains, consisting of Mesozoic and older rocks, rise up at this side, e. g. in the province of Segovia. They are absent at the foot of the Sierra de Gredos near Avila, but more westward they form again the spurs of the Sierra de la Peña de Francia as far as Salamanca. At the northern margin of the Central Mountains exists a pediment, higher than 900 m, not covered by Tertiary deposits.

The eastern borders are the most irregular. The ranges of the Sierras de la Demanda and de Urbión with their spurs stretch out to the W, like peninsulae washed by Tertiary deposits, which extend to the E into two straits. One, in the south-eastern part, follows the river Duero and strikes against the mountains of the Cordillera Iberica, near Cetina de Aragón (prov. of Zaragoza). The other strait is to be found in the north-eastern part of the basin, called the "estrecho de Burgos", connecting the basins of the Duero and the Ebro. Notwithstanding the apparent continuity of the deposits, the Montes Obarenes form an orographic boundary between the two basins, in which is found the gorge of Pancorbo, (see fig. 1).

All these surrounding ranges cause the rivers to flow towards the Duero, which leaves the basin through a narrow gorge with a steep gradient in the W. This feature causes an important regressive erosion, which here carried away the Tertiary sediments and laid open the underlying Palaeozoic and granitic rocks. The general opinion in literature is that the river's equilibrium profile is greatly disturbed. But according to our opinion this profile has never been graded before. From Numancia, a few kilometres from its source,

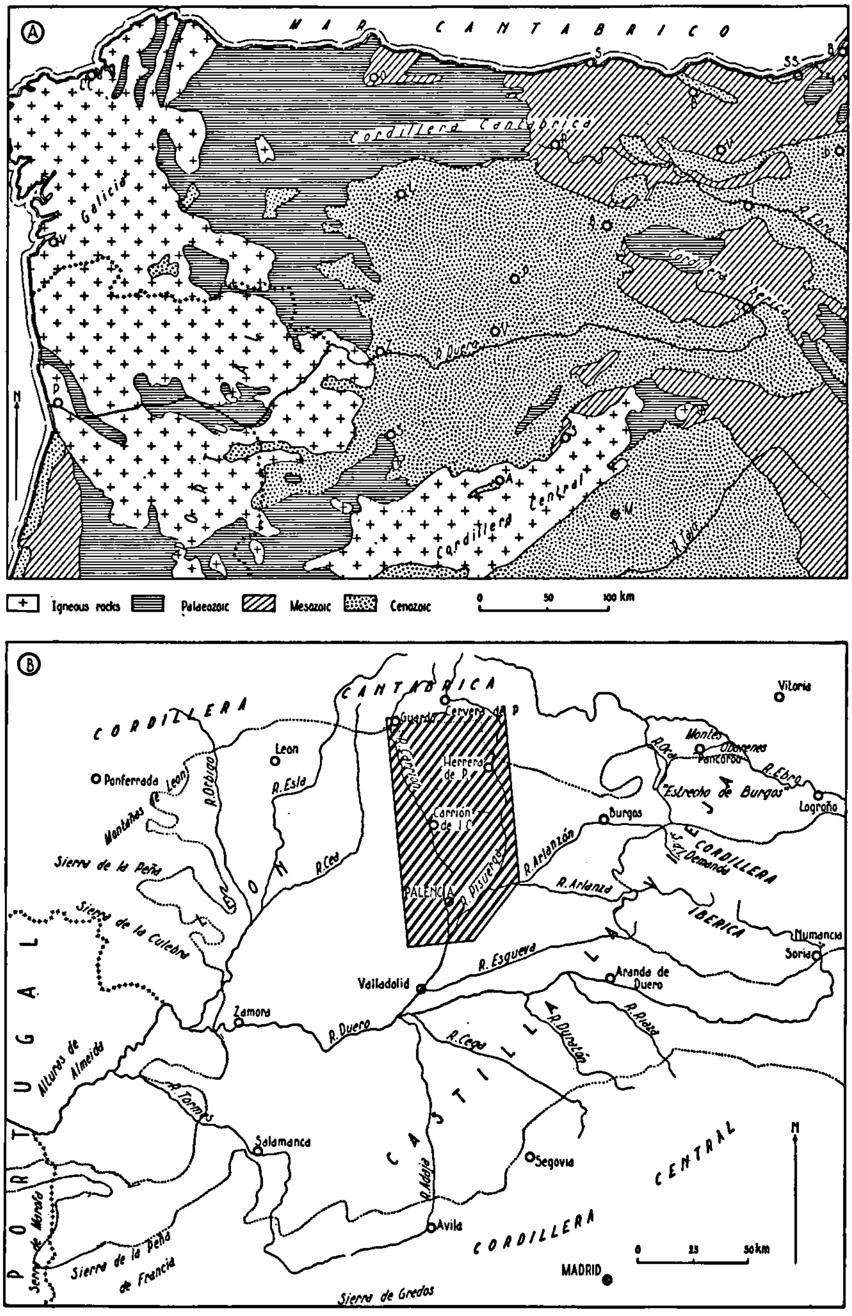

Fig. 1a. Geological sketch map of North-West Spain.
1b. The Duero basin, topography. The hatched region indicates the investigated area.

to Zamora the average fall is 0.8 m/km. Hereafter it suddenly increases to 2 m/km in Portugal. Morphologically the part of the river, flowing through the Spanish Meseta, can be considered as a pseudo lower course. In this part it receives the water of many affluents. From the N they come from the Cantabrian Mountains, as is the case with the Pisuerga, which together with its tributaries the Esgueva, the Arlanzón and the Carrión drains nearly the whole eastern part of the plateau. More to the W is the Esla, which with its tributary the Cea, carries off the water from the regions of León. The southern affluents of the Duero, coming from the Central Ranges, the Duratón, the Cega, the Adaja and the Tormes possess smaller drainage-areas with less tributaries.

In the plateau, especially in its large centre, two levels are to be distinguished. These are the lower level — *campiña* — with clayey deposits, covered by extensive corn-fields, and the higher level — *páramo* — with stoney, calcareous ground, barren and deserted. Between both are the slopes — *cuestas* — originating from fluviatile erosion, which produced long outcrops, particularly suitable to geological studies. Both levels pass into each other near the borders, especially in the western part. In the NE and the E the páramos extend to the surrounding mountains.

The climate is semi-arid, with rather great differences of temperature. The average annual temperature is low, because of the low temperatures of winter. Precipitation falls in two seasons, spring and autumn, with a total between 350 and a little over 500 mm annually. Some data are given in table I.

TABLE I.

Some meteorological data (after Hernández-Pacheco, 1934)

	height above datum level	average annual tempe- rature	average maximum tempe- rature	average minimum tempe- rature	average annual precipi- tation
Burgos	860 m	10.0°C	34.3°C	— 7.5°C	482.0 mm
Palencia	744 m	11.4	37.3	— 8.6	428.1
Valladolid	690 m	11.9	37.0	— 7.4	406.8

At present the region lacks nearly all natural vegetation. The páramos formerly had a cover of stone-oaks in the centre and oaks in the E. The campiña, outside the agricultural areas, had and has still a steppe-like vegetation. In the district of Zamora and Salamanca not all of the forest did disappear. In the surroundings of Burgos grow many poplars and mountain-ashes in the valleys. Nowadays various parts have been reforested, mainly with pines.

Deforestation in this region has been a fatal error. The oaks, the stone-oaks and the pines retained part of the precipitation, contributed to soil formation, and prevented soil-erosion. At present the plains with their flocks of sheep, feeding on the poor plant growth, give a disconsolate impression.

Agriculture is mainly concerned with the cultivation of wheat. In the proximity of the villages some horticulture is exercised, and many vineyards produce the great quantity of wine needed. Stock-breeding concerns chiefly sheep and goats, grazing on the fields in great flocks. Only in the Zamora-Salamanca region more cattle is found, (bulls for the bull-fights).

2. THE INVESTIGATED AREA IN THE PROVINCE OF PALENCIA

The northern border is formed by a geological boundary, namely in the E an unconformity, and in the W a disconformity, between the Mesozoic limestone and the Tertiary detritical, chiefly conglomeratic deposits. Ciry (1939) exactly located it. From Guardo on the river Carrión it extends eastward parallel to the foot of the Cantabrian Mountains, at a small distance from the base of the conspicuous escarpment. As the boundary is a zone of weakness small arroyos often have been developed along its course. Beyond Tarilonte it cannot be found in the terrain, because of its being covered by weathering soils with fields. Near the river Burejo it appears again. Passing over the top of Mount Matorral it curves slowly towards the SE into the direction of Nogales de Pisuerga. The Tertiary deposits having been folded together with the Mesozoic, the boundary becomes sinuous with tongues extending towards Barrio de Santa Maria and E of Cozuelos de Ojeda, respectively. N of Alar del Rey it passes the river Pisuerga and continues into south-eastern direction in the province of Burgos. In the E and the W the area is bordered by the rivers Carrión and Pisuerga, and southward it extends down to their confluence near Venta de Baños, (see fig. 2).

The whole area can be divided into various units, more clearly delimited in the S than in the N.

The north-western angle is occupied by the so-called Páramo of Guardo, a deposit of debris, having no relation to the real páramos in the S. It is a slightly domed area, in the centre of which the river Carrión is flowing. This river has no affluents all along its course through the Páramo of Guardo, the drainage pattern being divergent, so that all neighbouring courses turn away from the Carrión. More to the E the terrain is gently undulating with wide valleys and deeply cut arroyos. Seen from the Cantabrian Mountain Range the plateau gives the impression of being flat. But seen from a summit in the centre, its strong dissection and the rounded profiles of the interfluves are apparent. Most of the villages have been built in the river valleys and arroyos, but their fields often reach as far as the tops of the valley slopes. Higher-on scrub is to be found, and where this has been chopped, only heather. Reforestation, especially by pines, is increasingly going on, e. g. in the uninhabitated part of the valley of the river Boedo, between the villages Boedo and Bascones de Ojeda.

South of the line Herrera de Pisuerga—Saldaña the difference between campiña and páramo begins to be more apparent. The valleys of rivers and arroyos widen and have great flood-plains. The hills between them are mostly flat-topped. These are not páramos, because of their lithological difference compared with both the so-called Páramo of Guardo and the southern real páramos. This zone ends near a line from Carrión de los Condes, via Santillana de Campos to Osornillo. The so-called true basin facies is beginning S of this line. Between the rivers Carrión and Pisuerga the northern border of the limestone and marl páramo curves from the town of Palencia along Amusco to Melgar de Yuso. The area north of it is the region of fields in a lower level, which with the wide river valleys are

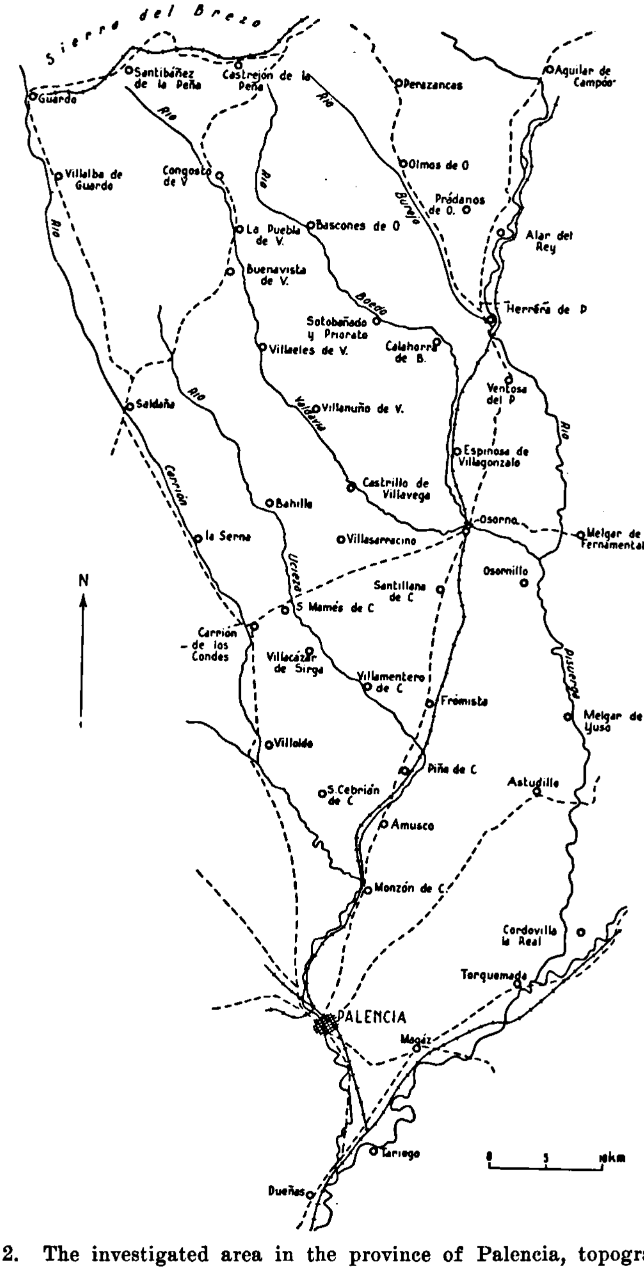

Fig. 2. The investigated area in the province of Palencia, topography.

called the campiña, or, particularly in the province of Palencia, the Tierra de Campos.

The drainage takes place by six major rivers, which are seldom dry, even in summer, although only three are coming from the Cantabrian Mountains. Because of the divergent drainage pattern in the Páramo of Guardo and through other influences, to be mentioned later, the river Carrión receives no affluents from the investigated area before Monzón de Campos, where the unimportant Ucieza flows into it. The rivers Valdavia, Boedo and Burejo are all flowing from NW to SE and debouch into the Pisuerga. This latter river is one of the most important affluents of the Duero and drains a total area of 14 526 sq.km (Vilá Valentí, in Solé Sabarís and others, 1954). In spring it is a savage river, especially after the melting of the snow, which in great thickness covers both the mountain area and the plains

Right through the full length of the area runs the Canal de Castilla with its side-branches. Commenced during the reign of Philip II the work was finished only in 1751. Until the construction of the railways from Madrid to the Basque provinces and Santander, it was the principal transportway of Castile. To overcome the great differences of height a number of sluices have been built. At present it has no significance as transportway, because of its narrow width and shallow depth. Together with its side-branches, Canal del Sur and Canal de Campos, its total length amounts to 207 km. Some villages draw their drinking-water from this continuously flowing canal. It is fed at Alar del Rey by the water of the Pisuerga. A project exists to put the canals into use again, not only for restricted shipping, but also for irrigation. A difficulty is that the villages, with few exceptions, are not situated at the canal, and so depend for their communications on the roads and the few railways.

After 74 km the canal bifurcates near Calahorra. The Canal de Campos, the western branch, here takes up water from the river Carrión. It traverses further-on a part of the province of Palencia and finishes after some 79 km near Medina de Rioseco in the river Sequilla. The Canal del Sur, the principal branch, is flowing towards the S, and runs nearly parallel to the river Pisuerga, in which it ends near Valladolid after another 54 km.

Besides the capital Palencia, with about 50 000 inhabitants, the province has two kinds of small towns and villages. The greater are regional centres, inhabitated not only by the farmers, who have their fields in the environment of the village, but also by the shopkeepers. In these villages are the new silos, flour-mills and frequently other small industries. The smaller villages consist, mainly, of farmhouses, grouped around the church with a school and a few bars. In this region it is necessary, because of the water supply, to build the farms concentrated in the villages, and not scattered amidst the fields. This often causes much loss of time riding to and fro. Until to-day most of the traffic is still very primitive, using donkeys, mules and ox-waggons. But gradually the more modern means of transport are being introduced.

CHAPTER II

PREVIOUS AUTHORS

For a long time, areas with horizontal, unconsolidated sediments have been more or less neglected in geological literature. After the earliest development of geology some studies appeared, but later on the interest considerably decreased. In this chapter we will mention a number of papers, dating from the past century, which deal with parts of the Duero basin and its borders. Most papers are geological maps with explanatory descriptions, or short notes about details on coal-bearing layers, on the nature of rocks, or on fossils, which are rather rare in this area.

After this chapter follows a bibliography of the older literature, up to about 1938, published on the basin in general, or on the studied area, with its surroundings and borders in particular. Besides the name of the author, only the title and the review, in which it has been published, will be given. Not all could be cited, the papers have been recorded so far as they could be obtained. The more modern papers, and also the older ones of great importance are mentioned in the general list of references.

One of the earliest papers is by Von Humboldt (1825), dealing with the origin and the climate of the Iberian plateaus. During the years 1837—1846 descriptions of the Tertiary deposits in Spain, especially by Ezquerra del Bayo, appeared in the review "Anales de Minas". W. I. H. (1850), commenting upon them, characterizes the Duero basin as a "gypseous tertiary freshwater".

Ezquerra del Bayo (1837, 1845), and De Verneuill & Collomb (1852) considered the Tertiary sediments of the Meseta to have been deposited in two extensive lakes, one in each of the two Castilian basins, which had their outflows through the surrounding mountain ranges. De Verneuill presumed enormous falls near Pancorbo, where the Duero basin was supposed to drain into the Ebro basin. The geologists of the last quarter of the 19th century, as for instance Cortázar (1877), Botella (1877), and later Mallada (1907), attributed the drainage by falls through the mountain ranges, to uplifts on the Iberian Peninsula at the end of the Tertiary. Mallada compared the Spanish Tertiary lakes with the recent North-American lakes.

An important point in the earlier papers was the question of the supply of so much water. Cortázar and Mallada ascribed this to great rivers, which flowed from a continent, situated in the north. Botella and Calderón (1884), on the other hand, considered it to be a consequence of a warm and very humid climate.

In opposition to the other investigators, who attributed the disappearance of the lakes to orogenic movements, Calderón (1895) supposed that changes of climate, tending to a decrease of humidity, caused a desiccation of the lakes. One of his arguments was the horizontal position and the extensive salt content of the deposits. Penck (1894) adopted the idea of a dry period within the Tertiary. On the basis of a flora found near

Oeningen (Germany), where at the time the 18°-isotherm was to be found, he deduced for the Iberian Peninsula a climate, such as nowadays prevails for example in Southern-Morocco.

The studies by Dantín Cereceda (1929, 1931) compare the present temporary lakes, which are nearly saturated with salts, especially the Laguna de la Nava near Palencia-town, with those on a greater scale during Miocene times, causing the extensive gypsum-bearing layers.

In 1896 Larrazet published his thesis, in which for the first time a stratigraphic-paleontological description of a part of the province of Burgos, and a bibliography of the papers written up to that date, are given. A number of subsequent papers nearly all deal with this subject. During the first decades of the 20th century important finds of fossil mammals, other terrestrial animals, and freshwater molluscs have been made. In the review of the Real Sociedad Española de Historia Natural many short notes and longer articles on this subject have been published. They describe not only the fossils, but also the layers in which they were found, and sometimes the adjoining layers (Dantín Cereceda, 1912, 1914; Ed. Hernández-Pacheco, 1912b, 1913, 1914a, b, 1921a, b; Miquel, 1902).

The discovery of an exceptional number of fossil mammals at Palencia-town in 1911 resulted, after a preliminary paper of Dantín Cereceda (1912), in the well-known, elaborate publication of Ed. Hernández-Pacheco (1915), in which, besides the paleontological description of what he called the Tortonian fauna, was included a geological study with a critical review of the papers published up to that time.

After Ed. Hernández-Pacheco it was especially Royo Gómez, who studied the Tertiary sediments of the Spanish basins. In a description of the molluscan fauna (1922), he first published a complete bibliography on the continental deposits of Miocene age in Spain. Later he paid some attention to the geology and the tectonics as well (1926—1934). During the International Geological Congress at Madrid in 1926, he guided an excursion into the Duero basin. Since then no more papers have been published on the true basin sediments.

Only recently Spanish sedimentologists took up such studies again, using modern methods. Up to now these have been limited to the Ebro basin, the small Tertiary basins north-west of it (Riba 1955a, b), the surroundings of Madrid (Benayas, Pérez Mateos & Riba, 1958), and the Catalan sediments (Virgili, 1958). As to paleontology a few new papers have appeared, viz. Saenz García (1934) and Bataller & Sampelayo (1944). In 1954 Crusafont Pairó & de Villalta Comella revised the datings of the fossils, which subject will be treated in chapter III.

More has been published on the areas at the borders. It are mainly studies on the mountains enclosing the basin, with only occasional remarks on the basin itself. Gómez de Llarena (1934) deals with the tectonics at the northern boundary of the basin. The Göttingen school (Germany) under Stille's direction undertook various studies during those years. Karrenberg (1934) worked on the Cantabrian Mountains, Schriel (1930) and Richter & Teichmüller (1933) on the Iberian Mountains. Others investigated the Central Ranges, and the mountains surrounding the other Spanish basins. Apart from these, Ciry (1939), studying the Mesozoic deposits north of the Duero basin, mapped accurately the boundary with the Tertiary sediments, and in that way could obtain some data which were very useful to our work.

Further, there are recent publications by Saenz García (1953) on the newer concept of stratigraphy and tectonics, and by Birot & Solé Sabarís (1954a) on the morphology of the western boundary of the basin, in which some phenomena in the middle and the eastern areas are mentioned.

TABLE II.

Sheets of the geological map of Spain on the scale 1 : 50 000 published up to 1958, only for the provinces of Palencia, León, Burgos and Valladolid.

number of sheet	name and province(s)	author(s)	year of publ.
133	Prádanos de Ojeda (Palencia)	Almela, A. and Badillo, L.	1956
134	Polientes (Santander, Palencia, Burgos)	Almela, A. and Comba, A.	1955
161	León	Hernández Sampelayo, P.	1932
162	Gradefes (León)	id.	1933
163	Villamizar (León)	id.	1934
167	Montorio (Burgos)	Cantos Figuerola, J. and Targhetta, J.	1952
168	Briviesca (Burgos)	del Valle, A. and Fernández Iruegas, P.	1933
194	Santa Maria del Páramo (León)	Hernández Sampelayo, P.	1928
195	Mansilla de las Mulas (León)	id.	1929
196	Sahagún (Palencia and León)	id.	1929
232	Villamañán (León)	id.	1931
235	San Cebrián de Campos (Palencia)	de Alvaredo, A. and Orti, C.	1952
237	Castrogeríz (Burgos)	del Valle, A. and Mendizábal, J.	1931
273	Palencia	—	1956
275	Santa Maria del Campo (Palencia and Burgos)	San Miguel de la Cámara, M.	1954
276	Lerma (Burgos)	id.	1953
313	Antigüedad (Palencia and Burgos)	id.	1953
314	Cilleruelo de abajo (Burgos)	id.	1950
345	Roa (Burgos and Valladolid)	id.	1953
346	Aranda de Duero (Burgos)	id.	1947
347	Peñaranda de Duero (Burgos)	id.	1954
374	Peñafiel (Burgos and Valladolid)	id.	1955
375	Fuentelcesped (Burgos)	id.	1952
427	Medina del Campo (Valladolid)	Badillo, L.	1956

The more important physiographical papers are those published by Dantín Cereceda (1912b), Ed. Hernández-Pacheco (1934), and Solé Sabarís and others (1952), with descriptions of geology, morphology, climatology, etc. of the various regions.

The first geological map of the province of Palencia has been drawn by Casiano del Prado (1861). More detailed maps of the province as a whole have never been published. Palencia is also one of the very few Spanish provinces, which is missing in the series of memoirs of the Spanish Geological Survey. Various authors published geological maps in their papers, however. The most important ones, dealing with the province of Palencia and the surrounding provinces León, Burgos, and Valladolid, have been published by Oriol (1876a), Aranzazu (1877), Mallada (1892a), Larrazet (1896), Mengaud (1920), Schriel (1930), Karrenberg (1934), Ciry (1939), and Cantos Figuerola (1953). Geological maps of the whole of Spain date already from the days of Ezquerra del Bayo (1851), Maestre (1864), de Verneuill & Collomb (1864, 1868), and Botella (1879). The Comisión del Mapa Geológico de España and the Instituto Geológico y Minero de España published several large scale geological maps, also dealing with the Duero basin. Finally in 1926 the publication commenced of the map on the scale of 1:50 000 with their respective memoirs. Those published on the provinces of Burgos, León, Palencia, and Valladolid are mentioned in table II.

Among the papers on the many borings drilled to obtain artesian water are those by Corugedo (1937), and Bataller & Sampelayo (1944), the latter treating the region of León in particular.

From all this we may conclude that most studies, which do not describe fossils, are concerned with the Duero basin as a whole or only with its borders. The sediments themselves and their gradual transition from the border to the centre have not yet been studied. The present paper, after a preliminary article by Pannekoek (1957), deals with one area, which was investigated in some detail. In adjoining parts preliminary work has already been done.

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CHAPTER III

STRATIGRAPHY

1. LITHOFACIES

In this first part of the chapter only the properties of the different lithological complexes, as they can be observed in the field, will be described. In other chapters the laboratory analyses will be treated.

The sediments have been classed according to their facies into six groups. The term facies is mainly used in this work as much as possible in accordance with the recently published definition of Teichert (1958). "Facies is the sum total of all characteristics of a sedimentary rock from which the environment of its deposition may be induced. Facies is thus, in the last analyses, an abstraction. It is, therefore, not a particular kind of rock, but something a rock has."

Fig. 3 shows the distribution of the sediments in the various facies in the investigated area.

Cuevas facies

In the N, just along the border of the Cordillera Cantabrica, coarse detritic sediments are exposed, presenting an alternation of conglomerates and sandstones. The best outcrops are found in the narrow valley of the small river, Rio de las Cuevas, a tributary of the river Valdavia. Therefore this facies was called the Cuevas facies (cuevas = caves).

The conglomerates consist mainly of limestone pebbles, derived from Cretaceous limestones, now exposed in a strip along the border of the Sierra del Brezo. They might be called boulder conglomerates, because of their rather high content of elements coarser than 256 mm. Their colour is grey, and that of their soils brown.

Between the thick conglomerate beds are found thin sandstone layers of a reddish-brown colour, which sandstones often have been eroded. At these sites there are now deep gullies (photo II).

The whole complex does not show any cross-lamination and other phenomena due to ordinary river sedimentation. It seems to be a sediment deposited as fans of torrents, which came from a mountain chain. The great thickness is a striking feature. In the valley of the Rio de las Cuevas, or in some other arroyos, the horizontal distance, perpendicular to the strike, of the zone with steeply dipping beds is about 1 km.

Ciry (1939) described a series of sediments, lying between the Maestrichtian limestones and the coarse conglomerates, and called by him "grès de Las Bodas", because of its outcrops near the village of Las Bodas in the region of Boñar, province of León. There it is developed as a sandy and calcareous complex, the clastic grains of which are nearly all quartz, resembling the Wealden facies in the Mesozoic. In our area he correlates these "grès" with the layers 3 to 8 of the outcrop in the Arroyo Pazo Brigaderos near Villanueva de la Peña, which is pictured in fig. 4. Here

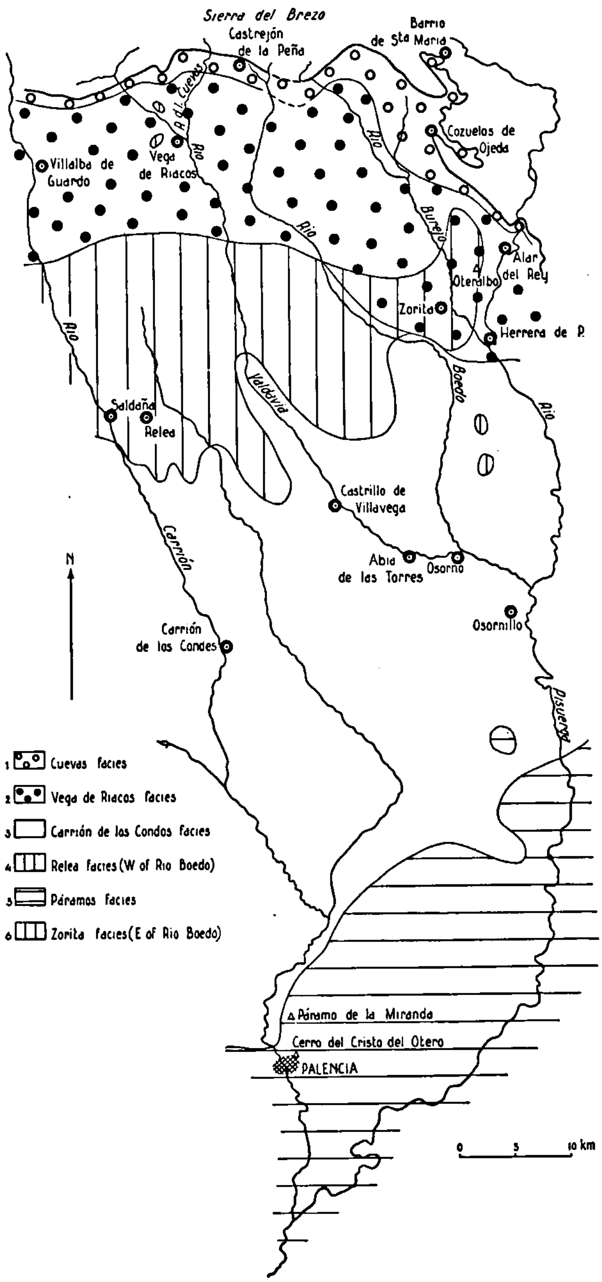

Fig. 3. Distribution of the Tertiary facies.

it lies conformably on the Mesozoic and is overturned with it. The complex also has been found S of the railway station Villaverde—Tarilonte, where it is a conglomerate of only small, subrounded, quartz pebbles, and more to the E, in the valley of the Rio de las Cuevas, N of the railway, where it is mainly a pink-coloured limestone (sample 2-007).

The strata in this Cuevas facies have been strongly folded together with the underlying Cretaceous sediments, and in the western part they are even overturned, as e. g. in the valley of the Rio de las Cuevas. After about one kilometre the dips suddenly decrease to low values. Cantos (1953) suspected the existence of a fault at that place, but this could not be proved. Some hundred metres further, the limestones conglomerates become nearly horizontal with only one slight undulation.

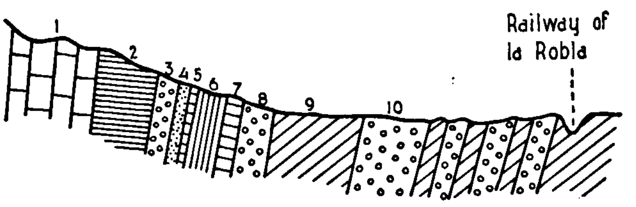

Fig. 4. Section through the Arroyo Pazo Brigaderos, East of the Rio de las Cuevas (after Ciry). Cretaceous: (1) Massive and sandy limestones, (2) Green shales. "Grès de Las Bodas": (3) Conglomerates with pebbles in various colours, (4) Fine pink sandstone, (5) Limestone (thickness 20 cm), (6) Some thin clayey and sandstone layers with a red colour, (7) Limestone (thickness 1 m), (8) Quartz conglomerate. Cuevas facies: (9) Clays, (10) Conglomerates and sandstones.

This zone of conglomerates and sandstones extends all along the boundary between Mesozoic and Tertiary. In the western part of the investigated area it is a narrow zone, mainly in overturned position, and conformable with the Cretaceous. Between Castrejón de la Peña and the eastern slope of the valley of the Boedo river it is not visible because of a cover of weathering soils and terrace gravels. In the eastern part the dips are smaller and the beds are no more overturned. There is a small angular unconformity with the adjacent Mesozoic limestones. The folding here was of another type than S of the Sierra del Brezo. Ciry gave a clear description of the orogenic processes in this region. As has been said in chapter I, the boundary becomes sinuous, with two tongues extending respectively northwestward to Barrio de Santa Maria (photo I) and southeastward near Cozuelos de Ojeda. The Tertiary sediments here consist only of a thin cover on the strongly folded older limestones.

The exact boundary between Mesozoic limestone and Tertiary debris is nowhere visible in the eastern part of the investigated area. It is a zone of weakness, which causes, along this boundary, the development of small arroyos (more or less wide valleys and gullies carrying water only in the wet seasons). But on two sites a deposit from very near the boundary is exposed. In an arryo near Barrio de Santa Maria and in another one N of Alar del Rey a coarse, strongly cemented breccia is outcropping, which is composed of debris from the adjacent Mesozoic limestones.

Summarizing it may be concluded from these field observations, that the coarse detritical sediments in the Cuevas facies were deposited at the border of a basin situated in the neighbourhood of mountain chains.

Vega de Riacos facies

At an average distance between 1 and 8 km from the boundary between Tertiary and Mesozoic, sediments with red and reddish-brown colour suddenly appear. These layers consist of alternately quartzitic pebbles bedded in sandy clays and similar sandy clays, without coarse detritus. Mostly they are nearly horizontal. Only in the northern part near the boundary with the sediments in the Cuevas facies small dips occur, which are, however, more probably of primary sedimentary origin than due to tectonic movements. Further to the S in the remainder of the investigated area the layers are almost horizontal. Royo Gomez (1926b), however, mentioned warping of the basin sediments SE of Palencia-town, (see also Ed. Hernández-Pacheco, 1915, photo lam. XXIII).

The red beds are exposed chiefly in the valleys of the rivers. One of the best outcrops is that near Vega de Riacos, in the valley slope of the river Valdavia (photo III). The Vega de Riacos facies occurs in a zone with an average width of 10 to 12 km, lying S of the Cuevas facies.

Within the Vega de Riacos facies some lithological differences can be observed. Just along the boundary with the limestone conglomerates the pebbles have a fairly large diameter and are subangular to subrounded. Between the two facies a disconformity exists. At some sites, e. g. in the valley of the Rio de las Cuevas, however, there seems to be a real conformable superposition. The coarse debris in the N are only found in the western part, as far as the valley of the river Burejo, where the geological boundaries curve towards the SE. Southward the particle size of the debris considerably decreases.

From the river Carrión in the W to the river Pisuerga in the E also a decreasing particle size of the sediments can be observed. In an exposure in an arroyo above the village of Villalba de Guardo, at the bank of the river Carrión, very coarse and angular blocks and boulders alternate with red and grey-brown layers, which are moderately consolidated. Here a thin lignite layer was found with its underlying, white-coloured zone of reduction. Unfortunately, only very few pollen were found, which are, moreover, strongly altered, so that they could not be determined.

Eastward, in the direction of the river Valdavia, the deposits in the Vega de Riacos facies are covered by younger detritical sediments. The gullies are not deep enough to expose the underlying red beds. Not until the valley of the Valdavia river itself, especially near Vega de Riacos, the red beds appear again. Here the pebbles are smaller and more rounded. The sandy layers contain a greater clay size ($< 2\,\mu$) fraction, and the colour is deeply red. The consolidation is stronger here, because there is a cement of calcite. With increasing consolidation the content of limestone detritus decreases. Possibly the calcite cement derives from the limestone pebbles. Near Villalba de Guardo some very small remains of limestone pebbles could still be observed; near Vega de Riacos they fail totally. Moreover an increasing cementation occurs where pebble layers pass into sandstone. Also the lime content increases.

Leaving the Valdavia valley and turning to that of the Boedo river, it appears that most of the sediments in this facies here also have a cover of terrace gravels and sands. Only in the more south-eastern part, where the river laid open its eastern valley slope, the red beds crop out again. Here they are represented almost only by red sandy layers with a greater clay size content than in the Vega de Riacos region. The same occurs more northwestward towards the valley of the river Burejo. Near the boundary with the sediments grouped into the Cuevas facies in this north-eastern corner, no very coarse detritic layers exist. They only contain small, slightly rounded, quartzitic pebbles, rapidly passing into coarse sandstones. West of Alar del Rey this complex directly touches the narrow zone of limestone conglomerates. More to the E along the river Pisuerga locally rather coarse red conglomerates occur. But at a distance of at most 3 km S of the Mesozoic the sediment again consists of sandstones and locally even red clayey marls and marls. In this region the deposits in the Vega de Riacos facies partly bear a cover of younger sediments belonging to another facies.

Considering the distribution of coarse and finer debris inside this facies, it seems probable that the supply came from the NW. Other arguments in favour of this opinion will be mentioned later.

Carrión de los Condes facies

A great part of the surface sediments of the Duero basin occur in this facies, called after the famous outcrops in the valley slope of the river Carrión, below the small town of Carrión de los Condes. They determine for a considerable part the character of the Castilian landscape with its monotonous yellow soils with corn-fields (photo VIII). It is mainly the zone of the campiña, the vast undulating plains.

Many previous authors described the deposits having this facies. San Miguel de la Cámara, for instance, author of the geological sheets of the eastern part of the Duero basin, gives the following description (translated) in the memoir on sheet 275 — Santa Maria del Campo (1954) — of the new geological map of Spain (scale 1:50 000):

"The Miocene consists, from below upward, of red clayey banks, used for bricks and tiles, and even for ceramics; of more impure clays, which serve for sun-dried bricks, used in some villages for the construction of houses, yards, walls of country-seats, etc.; of more light-coloured clays with sand and sparse pebbles, of slightly consolidated sands and sandstones, nearly always white or yellow; these sands and sandstones, which never contain mica, have variable grain sizes, ranging from that of the finest sands, used for scouring of floors and kitchen-utensils, to thick sandstones of the type "maciño"; of sands with abundant shingles and sandstones with small rounded quartzite pebbles, gradually passing into conglomerates, which form more or less extensive and thick banks ...

"The whole of the series, above all the sandstones, often shows cross-bedding, to be seen in various gullies and workings ...

"This sequence of clays, sands, sandstones and conglomerates is repeated various times; moreover, intercalated small tongues as well as lenses of sands of sands and gravels occur within the clay layers. Often the complex ends with more or less consolidated conglomerates, or when they are unconsolidated, the surface has the aspect of an alluvial plain, with quartz pebbles of the size of hazel-nuts, walnuts or somewhat greater, derived from the disintegrating conglomerates; this type of terrain is called in this region "guijares". The base of the series always consists, when exposed by erosion, of plastic clay, equivalent to the clay called "Tierra de Campos"."

This excellent description by San Miguel de la Cámara fully applies to the facies of the Carrión de los Condes in the investigated area. The deposits can be found S of the red beds of Vega de Riacos, in the whole southern part of the region. Locally, mainly in the N and in the SE, it has a cover of younger sediments having other facies.

Where in the N this younger cover has not yet been eroded, the underlying sediments in the Carrión de los Condes facies have been completely preserved. Real conglomerates are rare, and with them the gravels derived from their possible disintegration. But coarse and fine sandstones are exposed at various sites. True sands occur only in lenses between the more clayey sediments.

In the upper beds having the Carrión de los Condes facies a number of lime crusts has been found at different heights. Where these crusts have been disintegrated in outcrops, small pieces of lime are disseminated on the slopes.

Well-known outcrops in this facies exist S of Saldaña on the bank of the river Carrión (photo V), where they form the eastern valley slope. The same occurs at Carrión de los Condes, built on top of a valley slope. The outcrop of Abia de las Torres, W of Osorno, has been caused by the lateral erosion of the river Valdavia, and equally that near Castrillo de Villavega. Conspicuous are the deep gullies caused by strong erosion into these weak sediments, sometimes showing a badland topography (photo IV).

Below the small village of Osornillo, in a deeply cut arroyo running towards the Pisuerga valley, this complex is to be seen in its typical form (photo XIII). Here all sediment types as given by San Miguel de la Cámara alternate, it is here that can be seen good examples of cross-bedding, and it is here that really the origin of the sediments grouped into the Carrión de los Condes facies may be determined. In chapter V a full description of the Osornillo-complex will be given.

Relea facies

On palaeontological grounds a difference of age has been found between lower and upper deposits in some outcrops near Saldaña and Relea. But none of the investigators could find any lithological difference, except Ciry who mentions a lower complex with more clayey layers and a higher one with sandy sediments. In the lower complex the yellow colours are dominant, in the higher many intercalations of red to reddish-brown layers occur.

The macroscopic field description given for the sediments having the Carrión de los Condes facies can also be applied to this facies. The few differences have been mentioned above. Sandstones and conglomerates are not frequent. At some sites, moreover, the deposits should be called clayey and sandy marls, because of their high content of carbonate matter. To arrive at a better distinction of the two types, there had to be waited for the grain size analyses.

The lower beds in the Relea facies show the same thin crusts with their disintegration products as have been described for the Carrión de los Condes facies.

Páramos facies

In the south-eastern part of the investigated area, and farther towards the centre of the basin near the river Duero, white and grey sediments are outcropping in the valley slopes of rivers and arroyos. The slopes always rise up to a flat surface, sometimes with a red colour. This is the area of the conspicuous, white and grey marls, and gypsum layers, and the Páramos-limestones (páramo = desert) on top of them. Some layers sparkle in the light of the sun because of their great gypsum crystals. The marls and limestones are underlain by the yellow clayey sediments in the Carrión de los Condes facies (photos X, XI, XII). Figure 5, after Dantín Cereceda, shows

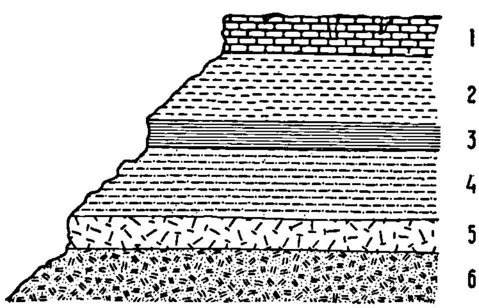

Fig. 5. Average section through the sediments in Páramos facies (after Dantín Cereceda). (1) Páramos-limestone, (2) Marls and gypsum, (3) Consolidated marls, (4) Marls, (5) Gypsum, (6) Sands and clays (in Carrión de los Condes facies).

an average section through the strata to be seen in the valley slopes, which are called *cuestas* by the inhabitants.

Many of the Spanish authors from the 19th and the first years of the 20th century, in particular Mallada (1907) and Ed. Hernández-Pacheco (1915), gave excellent descriptions of the sediments having this facies. The later authors refer to them.

On top of the yellow clayey layers in the Carrión de los Condes facies follows an alternation of grey gypsum-bearing marls and pure, white, fairly soft limestones, which are all exposed in the plateau slopes, and attain a total thickness of 100—120 m. Because of their weakness these sediments would have been rapidly carried away, if they had not been protected by the cover of very hard, blue to white-yellow limestone of the páramos, which varies in thickness between 2 and 20 m. Where this limestone is absent, only some small *oteros,* outliers, remained, e. g. the Cerro del Cristo del Otero near the town of Palencia.

The surface of the Páramos-limestone forms extremely flat plateaus, which are the higher parts of the Castilian basin landscape, as described in chapter I. The soils on the plateaus, on which some fields have been laid out, are of a brown to red colour. Ed. Hernández-Pacheco gives a detailed description of the slope of the "Páramo de la Miranda" (photo XII). The same slope has been chosen as type locality for a sedimentological investigation of this facies (see samples 6-001 to 6-016, chap. V).

In the investigated area the marl and limestone facies is limited to the south-eastern corner; moreover some small outliers occur in the adjoining campiña area, where they were protected by cemented terrace sands and gravels.

Data on the total thickness of the deposits of Miocene age (see part 2 of this chapter) are very scarce. Only recently Rios (1958) published some data on borings, drilled for the exploration of oil. One of these borings was executed near Burgos, and showed Miocene deposits having a thickness of 1198 m, then Mesozoic deposits having a thickness of 893 m, and finally Palaeozoic deposits.

Zorita facies

At a little distance from the Mesozoic limestone, near the river Pisuerga, a sediment complex with white layers, especially in the higher levels, is exposed. The elevated hill called Oteralbo, SW of Alar del Rey, with its white marls, rises above the red beds in the Vega de Riacos facies. The occurrence of these marls, sometimes consolidated to marlstones, is limited to a small region W of the Pisuerga. Infiltration of dissolved lime cemented a major part of the underlying red layers to sandstones and sandy marlstones. One of the best outcrops is above the little village of Zorita del Páramo, W of Herrera de Pisuerga (photo VI). The total absence of gypsum, and the intercalation of red layers, are strong arguments against its correlation with the sediments in the Páramos facies in the S. In the W this Zorita facies laterally passes into the Relea facies, so that the sediments in these two facies seem to be more or less contemporaneous.

Younger sediments

In a great part of the region between the rivers Carrión and Pisuerga a complex of coarse to fine gravel with sand covers the sediments of the formations described before. These gravels and sands are terrace deposits, mainly occurring near the valleys of the important rivers. Nearer to the Cantabrian Mountains the gravels occur in a wider area, and probably form part of a blanket of pediment debris. The gravels are much younger than the sediments described up to now, as appears from an unconformity between the gravelly cover and the underlying sediments of whatever facies.

Very near the boundary between Tertiary and Mesozoic deposits, on top of the valley slope of the Rio de las Cuevas, a remainder of a fan deposit of rather recent origin, though strongly consolidated, can be observed. It horizontally overlies the overturned conglomeratic beds of the Cuevas facies. Other fans, which often occur at the foot of the Sierra del Brezo, do not extend as far as the Tertiary basin sediments.

2. DATING OF THE DEPOSITS

In this part only the age determinations of the various deposits will be treated. It is thus mainly bio-stratigraphical.

Tertiary

In all publications the Tertiary deposits of the Duero basin have been divided into two groups of different age. The lower group is generally attributed to the Palaeogene, the upper group to the Neogene, or more exactly to the Miocene. Many datings are based on fossils, chiefly mammals, which, though not very rare in the area, have only been found in some outcrops, so that for the other outcrops the age can only be determined by careful correlation. For other, unfossiliferous, deposits age determinations have sometimes been given, based on correlations with dated deposits at great distance, often not even in the same basin; these can only be used with great caution. As this study is purely sedimentological, no independent age determinations have been carried out, and for the age of the various deposits, reference will be made to literature and to personal communications only.

The Palaeogene sediments. — Ed. Hernández-Pacheco (1915) mentions layers in the provinces of Zamora and Salamanca, which clearly differ from those in the other parts of the Duero basin. The fossils found in these beds at Corral (Zamora), such as *Lophiodon anieri* and *Crocodilus rollinati*, were dated as Eocene by several authors in the 19th century, and likewise by Ed. Hernández-Pacheco. Those of San Morales (Salamanca), such as *Palaeoplotherium minus* and *Xiphodon gracile*, were dated as Oligocene by Miquel (1906).

De Villalta Comella & Crusafont Pairó (1945) admitted an Aquitanian age for fossiles, which were found near Cetina de Aragón (Zaragoza), SE of Soria, in the uppermost part of the Duero basin, next to the Iberian Ranges, where the drainage is now directed towards the Mediterranean.

In the investigated area, and, more generally, along the borders of the basin, no fossils have been found in the older coarse detritic deposits. Nevertheless, many investigators considered them as belonging to the Palaeogene, the limestone conglomerates (in the Cuevas facies) being of Eocene age, and the red quartzitic conglomerates (in the Vega de Riacos facies) having an Oligocene age.

The limestone conglomerates in the NW of the investigated area overlie the Cretaceous limestone (Maestrichtian), either conformably or with a slight disconformity. In the E there is a small angular unconformity between the two. Ciry (1939) considers these conglomerates as having been formed in consequence of the Pyrenean orogenetic phase (Eocene), after which they have been folded together with the Mesozoic sediments. Generally this later folding is considered to have taken place during the Savian phase of Stille (Upper Oligocene to Lower Miocene, Royo Gómez 1926b, Ciry), which would mean, that the folded limestone conglomerates have a Palaeogene, probably Oligocene, age. We agree with these opinions. Similar horizontal limestone conglomerates may be syn- and post-tectonical with regard to this Savian phase, which means that their age would be Lower Miocene. For this we refer to chapter VI.

The Neogene sediments. — The deposits of the younger Tertiaries are generally classed as belonging to the Miocene. Earlier geologists, especially Cortázar (1877), attributed this age only to the uppermost deposits in the centre of the basin, that is the Páramos-limestone, so that the underlying marls and clays were placed by him in the Oligocene or "Proicene"; the conglomerates consisting of limestone components as well as those consisting of quartzite components were placed in the Eocene. Also Mallada (1907) adhered to this opinion.

Concerning the red beds in the Vega de Riacos facies, with their quartzite conglomerates, no reliable data can be obtained either. Their conformable or slightly disconformable position on top of the post-tectonic limestone conglomerates would suggest that their age is Burdigalian or later. As they are overlain by the deposits in the Carrión de los Condes facies of Middle and Upper Vindobonian age, a Lower Vindobonian age for the Vega de Riacos is also possible. But all datings of the deposits in this facies and in the Cuevas facies remain uncertain. In the following chapters these coarse detrital sediments will be treated without mentioning a specific geological age.

After the finds of fossil vertebrates and molluscs in the years 1911 and later, determined by Ed. Hernández-Pacheco (1915, 1921, 1930), the interpretation of Cortázar and Mallada had been proved wrong. The whole sequence of sediments in the basin centre apparently belongs to the Miocene. It includes a lower deposit with the clays and sands in the Carrión de los Condes facies, a middle one with the gypsum-bearing marls, and an upper with the Páramos-limestone, the two latter having the Páramos facies (fig. 5, page 56).

In the lower deposit of unknown thickness there is a sandy and pebbly horizon in a quarry in the Cerro del Otero hill near Palencia town, from which a well-known, so-called Tortonian, fauna has been extracted. Some vertebrates of this fauna are *Testudo bolivari, Dicerorhinus hispanicus, Listriodon splendens* and *Trilophodon angustidens.*

In the middle deposit with its gypseous marls only fossil eggs of *Anser* have been found at some places in the province of Palencia, outside the investigation area (Olavarría, 1898). The age, attributed by Ed. Hernández-Pacheco to this deposit, is Sarmatian, because of its situation between the lower, Tortonian, clays and the upper, Pontian, limestone, and of correlations with deposits in the Tajo basin.

The upper limestone is the Páramos-limestone, which has yielded various species of freshwater molluscs, as e. g. *Helix sanmigueli, Helix pradoi, Planorbis precornus,* and species of *Limnaea* and *Bythinia,* indicating a Pontian age (Royo Gómez, 1922).

Also in the region near Saldaña fossils have been found (*Testudo bolivari, Anchitherium aurelianense, Listriodon splendens* and *Trilophodon angustidens*). Ed. Hernández-Pacheco (1930) considers those of the lower beds to belong to the Tortonian, though to a somewhat younger level when compared with those from Palencia. Only the upper beds with *Hipparion gracile, Lycyaena chaeretis* and *Decennatherium pachecoi,* have a Pontian age. Similar Pontian fossils have also been excavated near the small village of Relea.

Bataller & Sampelayo (1944) gave a summary of the fossils found in the north-western part of the Duero basin (region of León). Many of the freshwater molluscs are attributed to the Lower Miocene. The mammals, such as *Trilophodon angustidens, Dinotherium giganteum* and *Palaeoplatyceros hispanicus,* may be dated as Middle-Miocene. Therefore the authors concluded that sedimentation in the León region commenced earlier, and possibly also finished earlier, than in the regions of Palencia and Burgos.

Crusafont & de Villalta (1945) corrected some determinations made by Ed. Hernández-Pacheco on the region of Saldaña. More recently (1954) they also revised all datings of the continental Miocene deposits of Spain. They propose not to use the terms Tortonian and Sarmatian, as the latter only represents a brackish water facies, and the former should be restricted to the marine Miocene. The continental deposits ought to be termed as Middle and Upper Vindobonian. The term Pontian remains unchanged, although in

Spain, especially in the basin of Vallés-Panadés, two levels can be distinguished in it, namely a lower level or Vallesian, and an upper level or Pikermian. The gypseous marls and limestones represent a part of either the Upper Vindobonian complex, or of the Lower Pontian complex. According to a written communication by Truyols, the fossils at Relea, a little E of Saldaña, are attributed to the Upper Pontian, those of the upper layers near Saldaña to the Lower Pontian, and those of the lower layers near Saldaña to a slightly later time than that of Palencia; that is to the Upper Vindobonian. The Palencia fossils themselves therefore must have a Middle to Upper Vindobonian age.

Summarizing the age determinations of the various Neogene deposits distinguished in the investigated area, it may be said that those in the Vega de Riacos facies are of uncertain age, those having the Carrión de los Condes facies may represent the Vindobonian, that the deposits in the Relea and Zorita facies belong to the Pontian, and that those having the Páramos facies include both Upper Vindobonian and Pontian. By means of sedimentological investigations a further confirmation of these data has been attempted. The results will be mentioned in chapters IX and X.

Quaternary

Earlier geologists considered most of the pebbly surface layers in the northern part of the Duero basin as belonging to the "Diluvium". Royo Gómez (1933) rejected this opinion, and thought only the terrace sediments to be of Quaternary age with the restriction that the highest terrace could be of Late-Pliocene age.

At present reliable palaeontological datings of the Quaternary deposits in the investigated area cannot be obtained either. The only fossil, found in a terrace deposit near Torquemada, at about 20 m above the present Pisuerga river, is a fossil *Equus* (Royo Gómez, 1934). We may add, though, that a generally accepted subdivision of the Quaternary for the Iberian Peninsula has not yet been established.

The debris covering the pediment found along the foot of the Cantabrian Mountains occupy a higher level than the highest terrace. They have therefore been attributed by various authors to the Upper Pliocene or Lower Pleistocene; many consider them to be of a Villafranchian age. This stage includes, according to the present opinion, the continental deposits of the Upper Pliocene and Lower Pleistocene. But in this area no fossils were found in them. In Spain there is only one fossiliferous locality with a Villafranchian fauna; viz. the famous excavation of Villarroya in the Ebro basin (summary by Crusafont & De Villalta, 1957). The latter investigator concluded, from the mammalian association, a humid, rather warm climate, with *lagunas* (see page 72), and savannahs, and forests on the mountain slopes. The pediment debris, however, indicate a deposition in a climate with strong wind action, a high temperature and a water supply by sheet-floods; that is, in a semi-desert. In other parts of Europe Villafranchian fossil-bearing sediments have been found to overlie this type of pediment debris (Cailleux, 1956). Recently, too, in Portugal (Ribeiro, Cotelo Neiva & Teixeira, 1943) and in the SW of Spain near Huelva (Riba, 1957, footnote on page 14), the pediment debris were found to be underlain by marine deposits from the Late-Pliocene. Up to now all reconstructions of climatic changes during the Villafranchian remain hypothetical. The present sedimentological investigations of the so-called Villafranchian pebbly deposits could not bring more data to light on this problem either.

The terraces found at various levels along the Spanish rivers are generally considered as being determined by climatic changes. All investigators agree that they are due to alternations of cold and temperate climates. The existence of two periods with glaciers in the higher Spanish Mountains, as e. g. Cordillera Cantabrica and Cordillera Central, is generally assumed. These are mostly thought to represent the last two glaciations. The earlier glacials may have only caused periglacial or even pluvial climates in the mountains. Ed. Hernández-Pacheco (1928), F. Hernández-Pacheco (1929), Baulig (1952), Cailleux (1956), and Woldstedt (1958) consider the terraces as correlative with glacial phases in the mountains. Solé Sabarís (1952), however, thought them to be interglacial.

Various investigators assume during the Pleistocene five or more glacials, instead of four, as did Penck & Brückner. The correlation between the glacials of the Alps and Northern Europe, and those in the Mediterranean region is not yet satisfactory established, and so it is impossible to give reliable datings of the gravelly deposits of the pediment and the terraces.

At lower latitudes, especially in the Sahara, the glacial stages of the temperate climatic belt are replaced by pluvial stages. Zeuner (1952) and Tricart (1958) consider the present data insufficient to correlate the pluvials with the glacials, but very recently Maarleveld & van der Hammen (1959) found indications that the pluvials of the lower latitudes indeed are contemporaneous with the glacials of the higher latitudes of the northern hemisphere. So it seems probable that the older glacial stages in Spain, and therefore also in our region, may have been pluvials.

CHAPTER IV

NOMENCLATURE AND CLASSIFICATION

Sediment nomenclature has always been a subject of debate. And still a generally accepted classification does not exist. The nomenclature used in this study has been mainly described by Pettijohn (1957). In one case we had to devise one which was more adapted to our purposes.

As grade scale the Wentworth-Udden-scale has been used, as recommended by the Lane Committee (Lane & others 1947), with two modifications (table III). One modification has been described, for instance, by Dunbar & Rodgers (1957), and concerns the substitution of the term gravel for the size classes 64—2 mm by the term pebble. The other was required because the method of analysis necessitated to use a clay size limit of 2 μ instead of 4 μ, which modification was also used by other investigators, for instance Bakker & Müller (1957).

TABLE III.

Modified Wentworth-Udden grade scale.

Boulders .	> 256 mm		
Cobbles .	256 — 64 mm		
Pebbles .	64 — 2 mm	Very coarse pebbles .	64 — 32 mm
		Coarse pebbles	32 — 16 mm
		Medium pebbles	16 — 8 mm
		Fine pebbles...........	8 — 4 mm
		Very fine pebbles ...	4 — 2 mm
Sand	2000 — 50 microns	Very coarse sand ...	2000 — 850 microns
		Coarse sand	850 — 420 microns
		Medium sand	420 — 210 microns
		Fine sand	210 — 105 microns
		Very fine sand	105 — 50 microns
Silt	50 — 2 microns	Coarse silt	50 — 16 microns
		Fine silt	16 — 2 microns
Clay size .	< 2 microns		

Several main sediment groups can be distinguished between the Cantabrian Mountains and the inner part of the Duero basin. In the field a preliminary distinction has been made between conglomerates, sandstones, sands, clays, marls, limestones, and evaporites.

Conglomerates are all sediments with a dominant fraction > 4 mm, which are more or less cemented, and contain rounded components. The two types, existing in the investigated area, are those containing more than 80 % limestones, being strongly cemented, and those with nearly 100 % quartzites, sometimes less consolidated. When necessary the terms boulder, cobble, or pebble were added, indicating the dominant gravel class. A further subdivision was not required, because of the limited extension of these sediments.

The sandstones are always consolidated by a carbonate cement. This cement almost exclusively occurs as calcite, sometimes as fairly large crystals, but commonly micro-crystalline. No sandstone appeared to have less than 25 % of calcitic cement. The samples containing less carbonate are unconsolidated. All sandstones have a certain percentage of silt and clay. When containing 20 % or more of clay and silt the name sandstone has not been used.

Because total grain size and carbonate analyses were available of the majority of the sediments, their results could be plotted in triangle-diagrams (see figs. 6 and 7). The sandstones occurring in the investigated area all lie in the segment between 25 and 60 % carbonate and 0 and 20 % silt + clay, and so have to be termed calcareous sandstones. When particles in the 2—4 mm fraction (very fine pebbles) were found, the term "extremely coarse" has been added. With increasing clay/silt content, and accordingly decreasing sand content, as shown in the centre of the triangle, the name sandy marl seems to be appropriate. Consolidated mixtures are then sandy marlstones. The clay/silt-carbonate mixtures with less than 20 % sand are the true marls (marlstones) and clayey marls. Several classes of limestones occur in the area: sandy limestones with a moderate sand size content, marly limestones and limey marls (marlstones) with a moderate clay/silt size content, and even really "pure" limestones, lying in the top segment, with over 95 % of carbonate matter.

In the case of gypsum-bearing marls and limestones the rocks have been plotted separately in the carbonate-sand-silt/clay triangle-diagram (fig. 7), without considering the gypsum content. But the term "gypseous" is always added, when the sediment contains gypsum. These gypsum-bearing marls and clayey marls generally are not consolidated, the gypseous limey marls only weakly.

Sediments containing 25 % or less carbonate are generally not consolidated. For these sands, silts and clays the triangle-diagram proposed by Shepard (1954) has been used. Because of the method of grain size analysis used, we had to consider as clay size fraction the parts < 2 microns, and as silt size fraction the parts of 2—50 microns. Only the central part of the diagram, called sand-silt-clay, needs in our opinion a shorter name. Though fully understanding the difficulties caused by previous misusing of the name, we nevertheless selected the term *loam*. In the field such loams have generally a crumb structure, as contrasted with the clays which are mostly very hard with a more prismatic structure. These differences are mainly caused by the present semi-arid climate with its warm and dry summers.

Nearly all samples contain a moderate percentage of carbonate matter, but for the sake of shortness we have not added the adjective calcareous to the terms. Moreover, the samples containing 5 % or less of soluble carbonate have been indicated by the term "pure".

The triangle-diagram as applied by Pustowalow & others (1944) divides the sediments into a much greater number of classes. It is true, that these more clearly show the sediment type by their respective names, but the boundaries of the sand size fraction (> 100 microns), of the silt size fraction (100—10 microns) and of the clay size fraction (< 10 microns) do not coincide with the size limits used outside of the USSR. Therefore we could not apply this diagram directly. Possibly a slightly modified from may later serve as a general base for nomenclature.

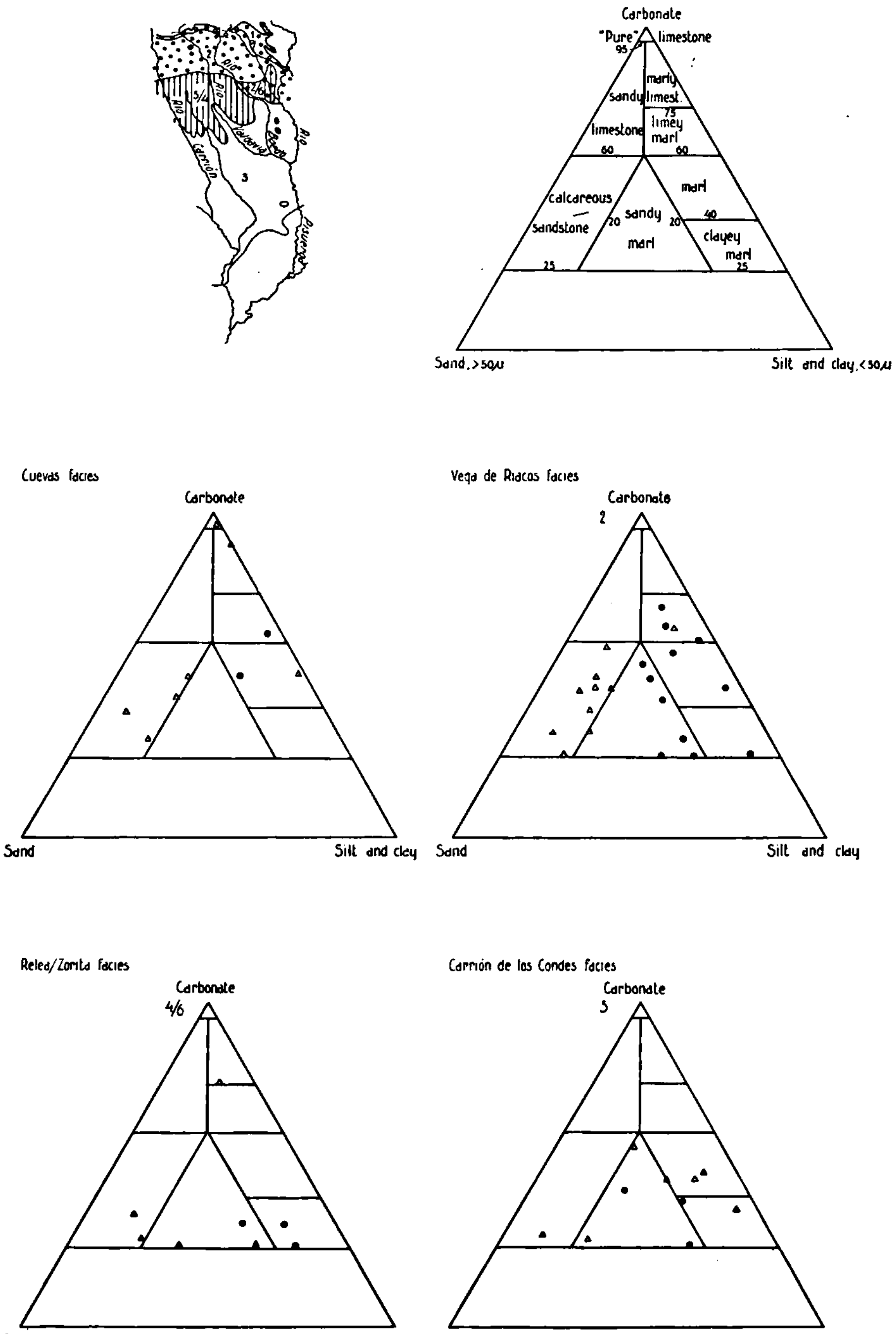

Fig. 6. Nomenclature of sandstones, limestones and marls. (The triangles within the diagrams represent cemented samples.)

When using the Shepard-diagram the nomenclature of the sediments departs from that of the grade scale given in table III. For a better distinction the modal size class(es) and the measure of central tendency (median value) have also to be considered (see chapter V). Where necessary auxiliary terms taken from the Wentworth-Udden scale were added for defining more exactly the character of the sediment.

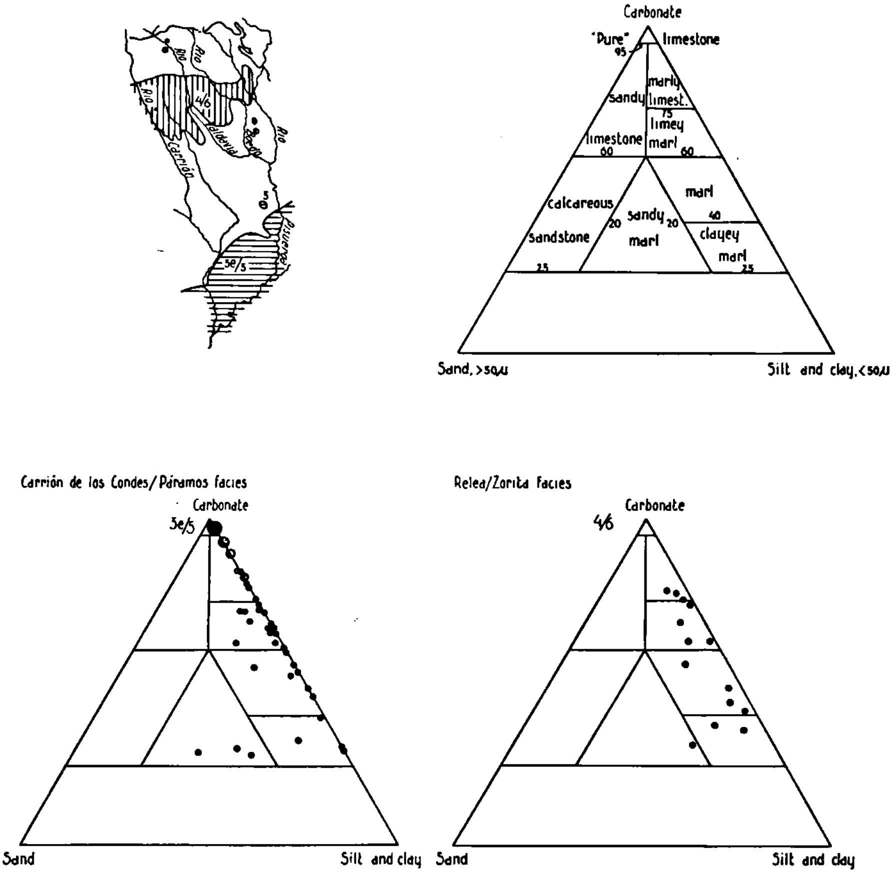

Fig. 7. Nomenclature of the white and grey layers in Relea, Zorita, and Páramos facies. (The cirkles represent the samples containing gypsum, the points those without gypsum.)

Sediment classes in the various facies

In the Cuevas facies exist, apart from the conglomerates, nearly only sandstones, belonging to the calcareous sandstone group. Weathered surface sediments fall within the marl and limey marl classes, because of their great carbonate content. The few limestones, nearly without a sand size fraction, are locally aberrant forms of the *grès de Las Bodas,* (fig. 6, triangle-diagram 1).

The Vega de Riacos facies is mainly characterized by the red bed sediment type. In the investigated area it is represented by conglomerates, sandstones and finer clastics. Generally they contain a certain percentage of fine-grained carbonates, derived from the source area. The sandstones, therefore,

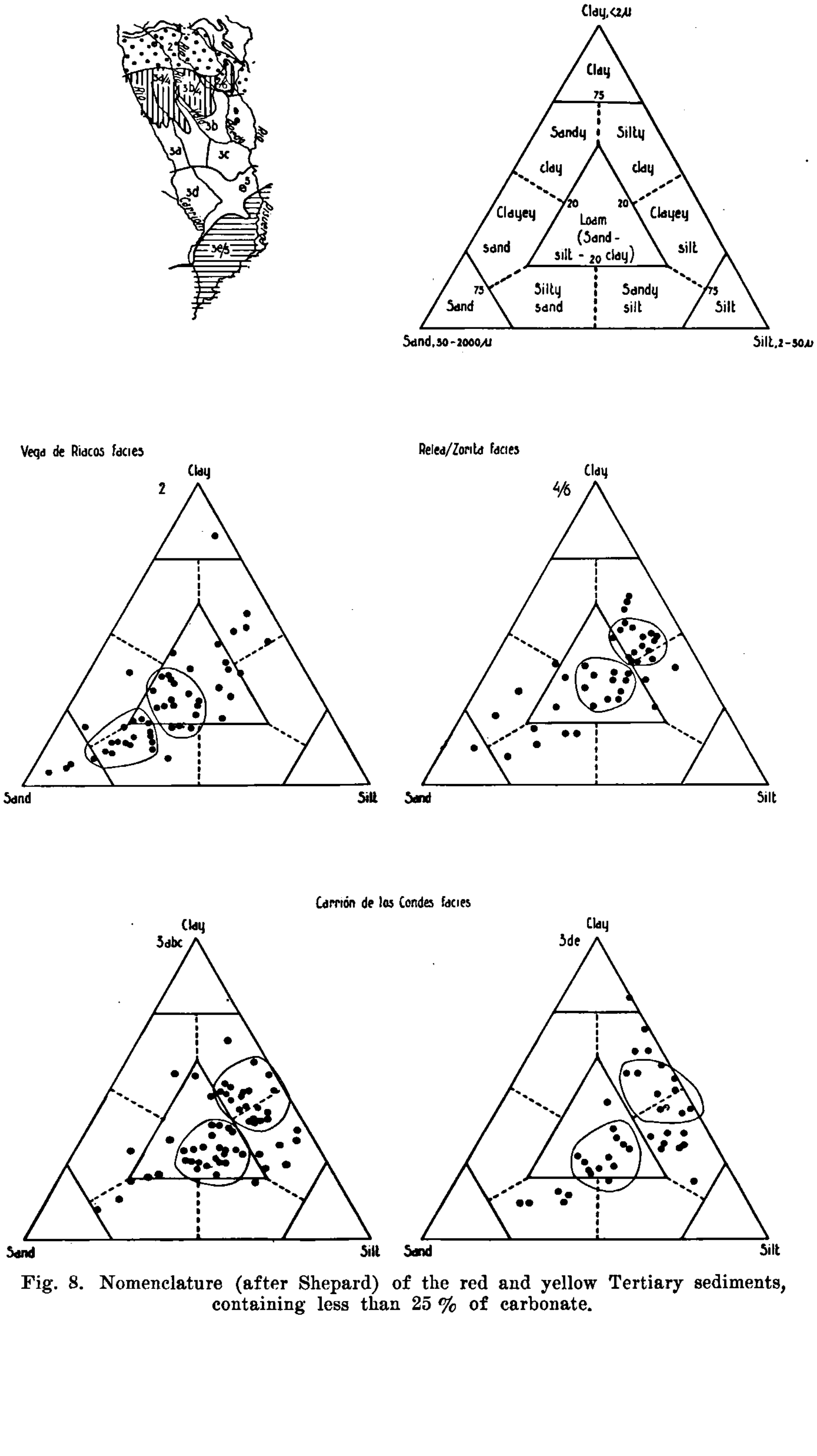

Fig. 8. Nomenclature (after Shepard) of the red and yellow Tertiary sediments, containing less than 25 % of carbonate.

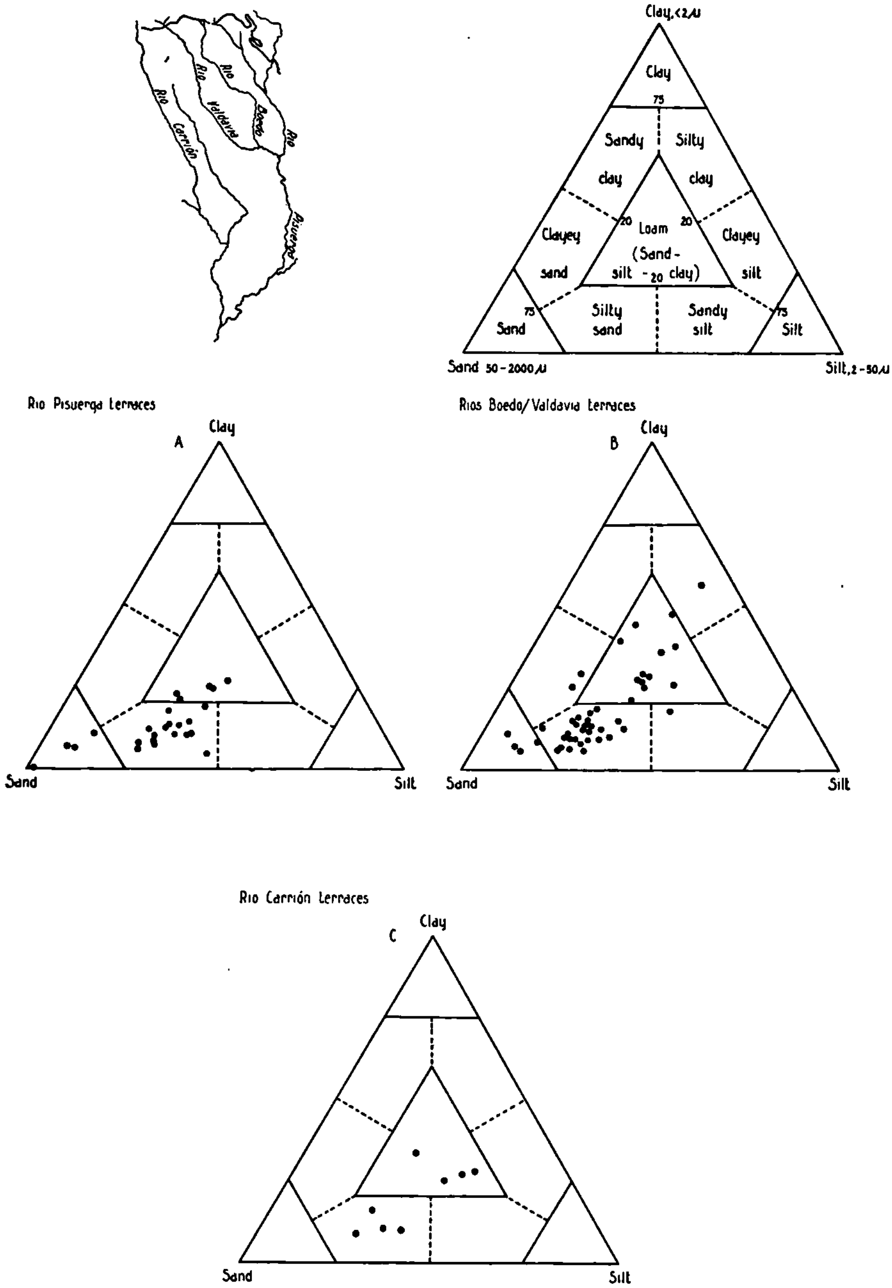

Fig. 9. Nomenclature (after Shepard) of the river terrace sediments.

ought to be called calcareous sandstones. The unconsolidated red layers with much lime are sandy, limey, clayey and "true" marls (fig. 6, diagram 2); the sediments with less than 25 % lime are rather coarse, and mostly fall within the sand, silty sand and loam classes of the Shepard-diagram (fig. 8, diagram 2).

The sediments in Carrión de los Condes and in Relea and Zorita facies have a finer medium grain size. The more or less consolidated, and therefore strongly calcareous layers are relatively low in number (fig. 6, diagrams 3 and 4/6). They generally do not contain more than 60 % carbonate and less than 20 % sand. Unconsolidated carbonate-rich sediments are sandy and clayey marls. The majority of the less calcareous layers, generally of yellow colour, belong to the loam, silty clay and clayey silt classes (fig. 8, diagrams 3abc, 3de and 4/6). The points in these classes lie in close groups in the triangle-diagram rather than scattered all over the segment. These close groups are taken together in presenting the grain size analyses.

The Páramos facies includes all white and grey sediments exposed in the S of the investigated area. The yellow layers below these beds, and also those locally intercalated between them, have been mentioned with the 3e-region of the Carrión de los Condes facies. So all deposits in Páramos facies have a high lime content. Diagram 5 (fig. 7) shows the white and the grey layers, which have been marked by two different symbols indicating the presence or absence of gypsum. The so-called *Páramos-limestones* can all be found in, or slightly below the pure limestone segment of the triangle. The gypsum-bearing sediments are more or less limey and mostly do not contain a sand size fraction > 50 microns. The layers containing more sand are weathered sediments; those without gypsum are the soils on top of the Páramos-limestones.

The samples from the terraces, without their fractions coarser than 2 mm, were also plotted in the Shepard-diagrams. From these (fig. 9) we can see that the greater part are silty sands. If they have been mixed with the underlying yellow sediments in Carrión de los Condes facies and in Relea facies, they have become loams. The prevailing colour is then yellowish-grey.

Colours of the deposits

The colours of the various sediments were estimated according to the method described by Cailleux & Taylor (1952).

CHAPTER V

GRAIN SIZE DISTRIBUTION

In this chapter will be treated, besides the grain size distribution of the various sediments, also the lithology of some special sediment types. It are the evaporites occurring in the S of the investigated area, the deposits of the type locality of the Páramos facies, and the sediments from the Osornillo outcrop.

Methods of investigation

We used the international method of grain size analysis, though sometimes slightly changed according to an unpublished report of "Zuiderzeewerken".

For most of the samples the combined sieve-pipette method (Robinson) was used. This method is not wholly satisfactory, especially for the exact determination of the percentages at the transition from the sieve method to the pipette method. The fraction 50—16 μ was determined by the sieve method, the part 32—16 μ was pipetted. The fraction 50—32 μ so was obtained by substraction. In these two fractions irregularities may be expected. But it is the most practical method, and the least time-consuming. It also has the advantage that comparisons can be made with the results of other laboratories, as e. g. that of "Zuiderzeewerken" at Kampen (Netherlands) and the Physical Geographical Laboratory of the Amsterdam University, where at present many samples from Surinam (Central Guyana) are being analyzed by using this method.

The samples are pretreated by H_2O_2 6 % and 2 N HCl, to remove the organic matter and the other soluble components respectively, such as carbonates, free iron oxides, gypsum, etc. Hereafter the residue is boiled with a peptizer (a solution of 0.04 N Na_2CO_3 + 0.1 N $Na_4P_2O_7 . 10\ H_2O$) in order to disperse the clay particles. The fractions < 32, < 16, < 8 and < 2 μ are taken with a Robinson-pipette, which method is based on the settling velocity of the small particles. The remaining part is freed from all particles $< 16\ \mu$ by means of an Atterberg sedimentation cylinder. The sand is then sieved in the Ro-Tap automatic shaking apparatus, containing 10 sieves with woven wire meshes, with the exception of the coarsest size sieve which is a sheet-screen. The diameters used are 1400 (= 1190, wire mesh), 850, 600, 420, 300, 210, 150, 105, 75 and 50 microns, which are thus nearly the midpoints of the Udden $\sqrt{2}$-scale. In this way a general idea of the grain size distribution is obtained. Samples with a fraction > 2 mm, and cemented samples, are pretreated in a slightly different way, but the final sieve-pipette analysis remains the same.

From some hundred samples only an incomplete grain size analysis could be made. In these cases at least the whole of the sand fraction, the silt fraction and the clay size fraction have been determined, in using a method introduced by Dulac & Bouat (1951), but adapted to our purposes by changing the size fraction boundaries.

According to this method, the samples are pretreated with H_2O_2 20 %, after which a small quantity of concentrated HCl, is added. Then some drops of a ION NaOH-solution are added, not only to neutralize the excess acid but also to peptize the solution. In the decanted suspension of all particles $< 16\ \mu$ a separation is made between the particles $< 16\ \mu$ and $< 2\ \mu$ by means of the Robinson pipette. The residue of the decantation ($> 16\ \mu$) is dried and sieved by a 50 μ-sieve. In this way it is possible to determine the sand size (2000—50 μ), silt size (50—2 μ) and clay size ($< 2 \mu$) fractions, so that they can be plotted in a triangle-diagram.

Organic matter was determined by the rapid titration method of Walkley & Black.

Gypsum determinations were carried out gravimetrically (for the methods see Piper 1950).
For determining the carbonate content the Scheibler-method was used, by which the sediments are treated with HCl, and the freed CO_2 is determined volumetrically.

The acidity or alkalinity (pH) of the sediments, which was determined in an aqueous suspension, may sometimes be important for the recognition of the depositional environments of the sediments. More often, however, the present pH-value of a deposit is a consequence of weathering. Where it had any importance, the pH-values were mentioned in the respective paragraphs.

Graphical representation and statistical values

For presenting the grain size distribution of the various sediments found in the investigated area cumulative frequency curves have been mostly used; histograms have only been applied in some special cases. It must be noted that the equal widths of the bars in each histogram apply only to the size classes $> 32\ \mu$. The smaller size classes may, therefore, not be compared with the coarser size classes, although some conclusions on the sediment type may be drawn from it. The height of the bars, and not the surfaces represent the respective weight percentages of each size class.

The graphs chosen for the cumulative curves are those having along their Y-axis the weight percentages on an arithmetical scale, and along their X-axis the size diameters on a logarithmic scale. Graphs with an artihmetical size scale, as used by Doeglas (1941) have the disadvantage that especially the distances between the points of plotting become too great for the coarse sizes and too small for sizes < 8 microns. A normal percentage scale instead of a Gaussian probability scale is used, for instance, by Pettijohn (1957) and by Preobraženský & Sarkisjan (1954).

The size boundaries in this work are given in millimetres and microns. Table IV may serve to compare this mm-size-scale with the φ-scale ($\varphi = -{}^2\log$ diam in mm, Krumbein 1934), which is much used in other countries.

TABLE IV.

μ	φ	μ	φ
1700	—0.76	105	3.25
1190	—0.25	75	3.74
850	0.24	50	4.33
600	0.74	32	4.97
420	1.25	16	5.97
300	1.74	8	6.97
210	2.25	4	7.97
150	2.74	2	8.97

Of the samples lying close together in the nomenclature diagrams of Shepard (chapter IV), the cumulative curves have been united to zone diagrams; the average sample of such a group of samples has been presented as a histogram in an angle of the graph.

The following statistical values were determined: *Md* (median or 50 percentile), Q_3 (25 percentile of the cumulative curve), Q_1 (75 percentile), *So* (coefficient of sorting: $\sqrt{Q_3/Q_1}$) and *Sk* (coefficient of skewness, symmetry:

Q_3Q_1/Md^2), in its form $^{10}\log Sk$. Following Trask (1932), sediments with a *So*-value of 2.5 and smaller have been called well sorted, of 3.0 to 4.0 normally sorted, and of 4.5 and greater poorly sorted. When using the value $^{10}\log Sk$ for the symmetry, 0 (zero) means a perfect symmetry; positive values indicate a skewness whereby coarse admixtures exceed the fine, negative values indicate the converse.

The coefficient of kurtosis, $(Q_3 - Q_1)/2(P_{90} - P_{10})$, was not determined, because most sediments have a clay size fraction of more than 10 per cent, so that the 90 percentile could not be measured. A great number of sediments even contain more than 25 % of clay size fraction, and in these cases even the 75 quartile could not be determined, and consequently neither the sorting, nor the skewness.

Another statistical value is the so-called *q*-value, introduced by Hissink (1929), and later used e. g. by Zuur (1936, 1943), Wiggers (1955), Bakker (1955, 1957a), and Bakker & Müller (1957):

$$q = \frac{\text{fraction} < 2\,\mu}{\text{fractions} < 16\,\mu} \times 100.$$

This value is important as an indicator of the salinity of the depositional environment of recent sediments, but is is known that with increasing age of the deposits the *q*-values decrease. This is chiefly a consequence of diagenesis, which causes a slight cementation of the clay particles by SiO_2, so that the weight percentage of the size class $< 2\,\mu$ decreases. Even Pleistocene sediments have already lower *q*-values than Holocene sediments.

Interpretation of the curves

The conclusions to be drawn from the shape of the cumulative curves concern the transporting medium, and the differentiation and mixing of the deposited particles. Doeglas (1946, 1950) distinguished three types of size frequency distributions in homogeneous deposits or thin layers. Stratified and heterogeneous deposits all have mixed types; the ratio of the (respective) amounts of each type in a sediment gives an indication on the origin of that sediment.

Very rarely a sediment in nature shows a symmetrical curve, and nearly always it is of a mixed type; this also applies to the investigated area. Of more than 600 samples analyzed, not one has a $^{10}\log Sk$-value $= 0$, and only three have a value of nearly zero.

Bakker & Müller (1957), however, emphasized that the processes of sedimentation are very complicated, and that, for instance, soil formation strongly influences the grain size distribution of a deposit.

All Tertiary and Quaternary sediments in the Duero basin are continental deposits. Therefore only fluviatile, lacustrine, aeolian, glacial or talus deposits need to be considered.

A strong aeolian agent may be excluded. Such deposits generally have a homogeneous size frequency distribution. Grains $> 500\,\mu$ are mostly absent. Small particles of silt and clay size only settle in sheltered places, or when the wind ceases (loess). Not a single grain size distribution of sediments in the investigated area shows a curve typical for full aeolian deposits. But there are some indications that a slight aeolian influence may have occurred.

Glacial sediments are limited to Quaternary times, and are only found in Spain within the mountain ranges, never in the plains. Sediments deposited during Quaternary glaciations, as e. g. river terraces, do occur in the investigated area, but are not of glacial origin themselves.

Talus deposits are mostly coarse. Grain size analyses of the fine fractions do not provide a means of distinguishing this type of sediment.

Lake sediments generally contain considerable amounts of the fine fractions. Because of the weakness or absence of currents, coarse particles rapidly lag behind, and are deposited in river deltas and on the shores. The cumulative curves of lake sediments therefore must have their steep part in the fine grain sizes. In the investigated area some sediments may have been deposited in lakes or at least in stagnant water. Temporary lakes, pools and marshes are called *laguna* in this region. This word will be used further to indicate such depositional environments.

Fluviatile sediments form the greater part of the continental deposits in the investigated area. In order to recognize them, and to determine their possible mixing with lake deposits, and, along the mountain foot, with talus deposits, the different types of river sediments have to be distinguished. Doeglas (1946, 1950) figured the mixing of bottom material and fine suspended materials in various proportions on probability graphs with an arithmetical size scale. These curves have been transferred to logarithmic graphs, as used by us, in fig. 10. Curve A represents the bottom material, E the

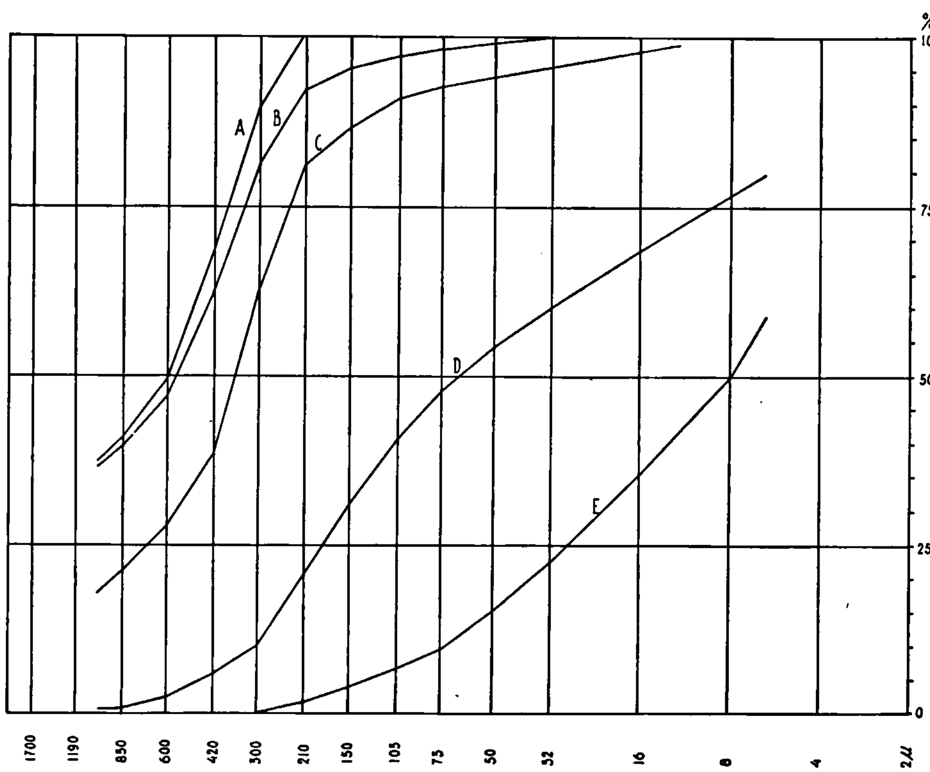

Fig. 10. Cumulative curves of size composition of calculated mixtures of bottom material (A), and fine suspended material (E) of river sediments in various proportions (B, C, D), modified after Doeglas.

suspended materials, B, C and D mixed types. Fluviatile sediments thus can spread out over nearly the whole range of the diagram.

Mohr & van Baren (1954), Bakker (1955, 1957a), and Bakker & Müller (1957) found that many river sediments deposited during high water have a bi- or sometimes tri-phasic character. This means that such sediments show two or three maxima in their grain size distribution, and especially a very low percentage in the silt size fraction. Similar distributions also occur in tropical, humid climates in weathering products of some parent rocks (Bakker & Müller).

These authors distinguish three groups of bi-phase sediments:

group A,	with a clay size content of	10— 30 %,
B,		30— 50 %,
C,		50— >70 %.

It should be noted, however, that with increasing clay content the other maxima, which mostly occur in the sand size fractions, become lower, so that most deposits of the C-group, and also many of the B-group lose their bi-phasic character.

Cuevas facies

The sediments are mainly conglomerates and sandstones. Only in the so-called "grès de Las Bodas" of Ciry, some limestones locally occur.

Grain size analyses in the laboratory have only been made of the sandstones, the matrices (< 4 mm) of the conglomerates and the pink-coloured limestone of the Las Bodas layers. In the field we have determined the ratio of the finer and coarser elements of the conglomerates. On 1 m^2 30—40 % of the surface consists of particles smaller than 4 mm and pores, and 15—20 % of the particles have a greatest length between 4 and 20 mm. Thus the coarser gravel components occupy only 40—55 % of the surface and they generally do not touch each other. The proportional percentages of these pebbles, cobbles and even boulders of some samples have been mentioned in chapter VI.

The cement is always calcitic, and is present in the sandstones in percentages of 30—50 %. The matrices of the conglomerates have nearly the same composition as the sandstones. Cumulative curves of the non-soluble mineral components of some samples are given in fig. 11; table V gives the composition of some sandstones and conglomerate matrices, and the pink-coloured limestone of the Las Bodas layers (sample 2-007).

It appears, that the sandstones and matrices, with the exception of sample 2-004, generally have the same mineralogical composition. Also the lime content lies within the same range. A remarkable feature is the relatively high percentage of clay size particles. This fine material may possibly have filled up the pores between the sand grains, leaving the pores within the clay for the calcitic cement. In the cases where the carbonate content is high this cannot be due to filling up of voids by carbonate, and has to be attributed to other causes. It may be that limestone grains have dissolved during the preliminary treatment. Sample 2-007, only mentioned in table V, is a "pure" limestone. The grain size distribution of carbonates was not determined, but it can be said that the carbonates are moderately to finely granular.

Most samples are well or normally sorted. The negative logarithmic skewness values indicate an asymmetry towards the finer grained components

No correlations between mean size and sorting, or between mean size and skewness, are apparent.

The curves are all steep in the sand sizes. The samples 2-006 and 2-017, both matrices of conglomerates, have their maximum size classes in the coarse sand sizes; the sandstone samples, however, have their modal classes in the fine sand sizes. Some samples have a second maximum in the clay size fraction.

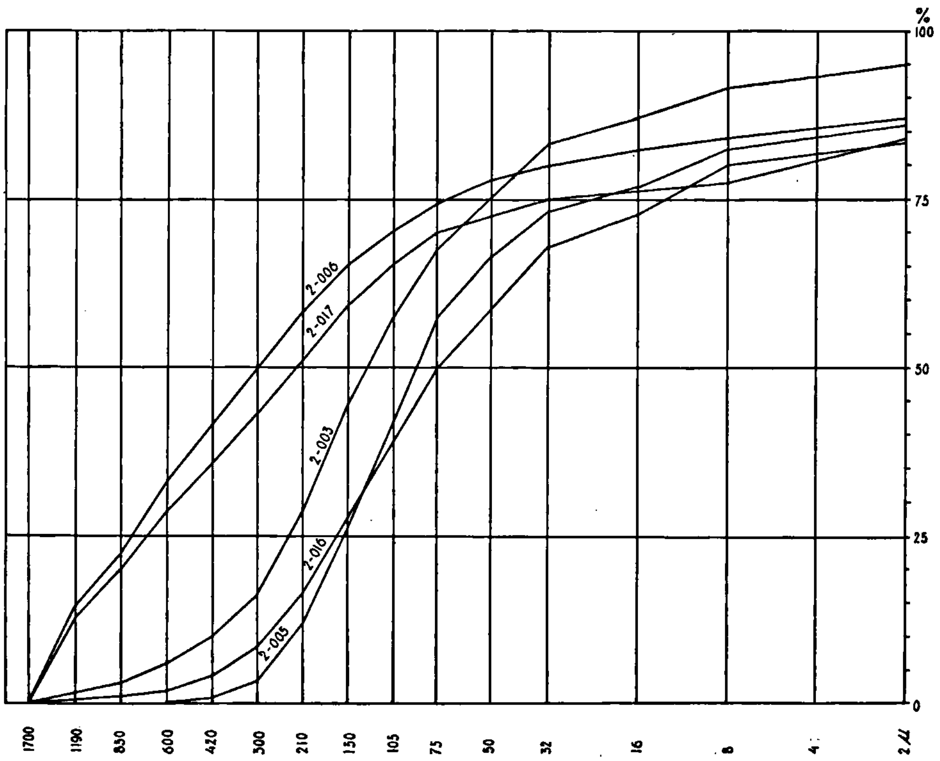

Fig. 11. Size frequency distributions of the non-soluble mineral components of some sandstones and matrices in Cuevas facies.

As to the origin of these sediments, a mixing of river deposition and fan deposition may be presumed. This cannot definitely be concluded from the grain size analyses only. Here the help of other analyses, such as the pebble roundness determinations, is necessary.

Vega de Riacos facies

The sediments in this facies chiefly consist of beds of conglomerates and sandstones, more or less consolidated, and finer sandy and marly layers between them, all with a striking red colour. From the W towards the E the conglomerates pass into sandstones. The intercalated, mostly unconsolidated, red sandy beds, however, have in the whole region of this facies nearly the same granular composition. The conglomeratic layers are less cemented than

TABLE V.

Analytical data of some sediments in the Cuevas facies.

	name	> 2 mm	2000—50 μ	50—2 μ	< 2 μ	$CaCO_3$	Md	Q_3	Q_1	So	$^{10}\log Sk$
							in microns				
2-003	extremely coarse calcareous sandstone	1.1 %	72.9 %	20.0 %	6.0 %	31.1 %	130	228	46	2.23	— 0.20
2-004	matrix	1.9	5.5	12.9	80.0	32.9	2	—	—	—	—
2-005	calcareous fine sandstone	—	65.7	20.2	15.1	44.7	87	150	20	2.73	— 0.40
2-006	matrix	7.0	71.5	8.6	12.8	9.8	278	750	62	3.47	— 0.22
2-007	"pure" limestone	—	13.6	48.2	37.9	97.0	5.1	—	—	—	—
2-014	matrix	3.9	67.6	15.4	16.3	41.9	114	260	34	2.77	— 0.17
2-016	calcareous fine sandstone	—	57.7	24.9	17.2	52.1	70	157	12.5	3.56	— 0.40
2-017	matrix	9.3	65.2	10.5	15.5	31.0	210	660	22	5.46	— 0.48
2-019	matrix	14.0	64.1	8.3	13.8	30.0	235	590	36	4.06	— 0.42
2-099	extremely coarse calcareous sandstone	7.9	78.9	8.7	4.2	39.9	270	508	122	2 04	— 0.08

the sandstones. The red colour is caused by the presence of goethite, occurring as coatings around the sand grains.

Table VI represents data of some cemented sediments. The matrices of the conglomerates all contain a size class 2—4 mm, which is absent in the calcareous sandstones, which therefore can not be termed as "extremely coarse". Only those in the E near the river Pisuerga are a little coarser. The calcitic cement content is more variable than in the sediments in the Cuevas facies. In the region of Villalba de Guardo, at the banks of the river Carrión in the W, small limestone grains are found; this may be one of the causes of the lower calcareous cement content if compared with the

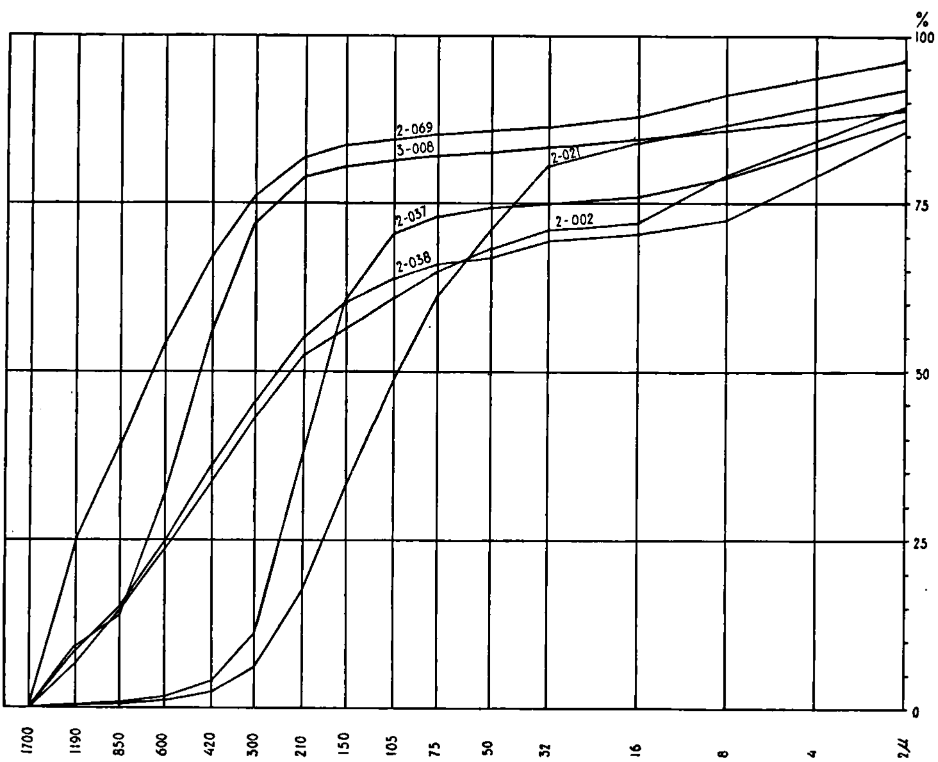

Fig. 12. Size frequency distributions of the non-soluble mineral components of some sediments in Vega de Riacos facies.

sediments from other outcrops. In the latter the high content of cement might be a consequence of solution of limestones, even in the source area, and a redeposition as a calcitic cement, which precipitates at a pH of 7.8 or higher. Most of the red beds now have pH-values between 8.0 and 9.0, but during the time of sedimentation these must have been lower, as can be concluded from the clay mineral associations (chapter VIII, part 3).

Fig. 12 shows six cumulative curves. At a glance three types of sorting can be distinguished, namely a poor sorting (2-002 and 2-038, both being matrices), a good sorting (2-021 and 2-037, both being calcareous medium to fine sandstones) and a perfect sorting (2-069, a matrix and 3-008, an extremely coarse calcareous sandstone). Whether these coarse sediments are

TABLE VI.

Analytical data of some cemented sediments in the Vega Riacos facies.

	name	> 2 mm	2000—50 μ	50—2 μ	< 2 μ	$CaCO_3$	Md	Q_3	Q_1	So	$^{10}\log Sk$
							in microns				
2-002	matrix	1.9 %	65.8 %	21.1 %	11.2 %	49.6 %	232	540	12	6.73	— 0.92
2-020	matrix	4.8	57.9	23.3	14.0	53.5	84	180	12	3.88	— 0.51
2-021	calcareous fine sandstone	—	69.6	21.5	8.9	33.3	92	169	40	2.06	— 0.14
2-026	matrix	20.1	56.2	3.4	20.3	6.6	285	670	2	18.51	— 1.79
2-036	calcareous medium to fine sandstone	—	77.7	8.1	14.2	26.2	177	298	60	2.23	— 0.24
2-037	calcareous medium to fine sandstone	—	73.7	13.2	13.1	46.1	173	232	22	3.25	— 0.76
2-038	matrix	4.6	63.6	17.1	14.7	48.5	245	575	5.6	10.13	— 1.28
2-063	matrix	3.9	66.2	9.4	20.5	54.2	440	805	4.1	14.12	— 1.78
2-066	extremely coarse calcareous sandstone	2.7	83.5	5.4	8.4	33.2	490	940	215	2.08	— 0.08
2-069	matrix	20.6	67.9	5.0	6.5	11.3	645	1100	300	1.99	— 0.06
3-008	extremely coarse calcareous sandstone	1.7	80.8	5.9	11.6	45.9	450	660	245	1.64	— 0.09
3-053	matrix	—	44.0	23.8	32.2	7.8	26	—	—	—	—
3-054	calcareous coarse to medium sandstone	—	73.3	15.0	11.7	59.6	225	363	44	2.98	— 0.54

mixed deposits of fluviatile and fan sediments, or only various types of fluviatile deposits cannot be concluded from these data.

The deposits containing less carbonate, as plotted in the Shepard triangle diagram (fig. 8, diagram 2), clearly show two groups, namely one chiefly in the silty sand segment and the other chiefly in the loam segment. Most coarser deposits occur in the W of the facies area. The loam deposits are frequent in the Valdavia region. The finer sediments can be found in the centre of the facies area. The E shows all types of deposits, even conglomerates, supplied through the valley of the present Pisuerga.

Of these two groups, zone diagrams of the cumulative weight-percentage curves are given in fig. 13 and 14. The histograms represent average samples of each group. Sample 3-062 (silty medium to fine sand) is from the outcrop of Villalba de Guardo in the W, sample 2-043 (loam to silty sand) is from the region around Alar del Rey in the E.

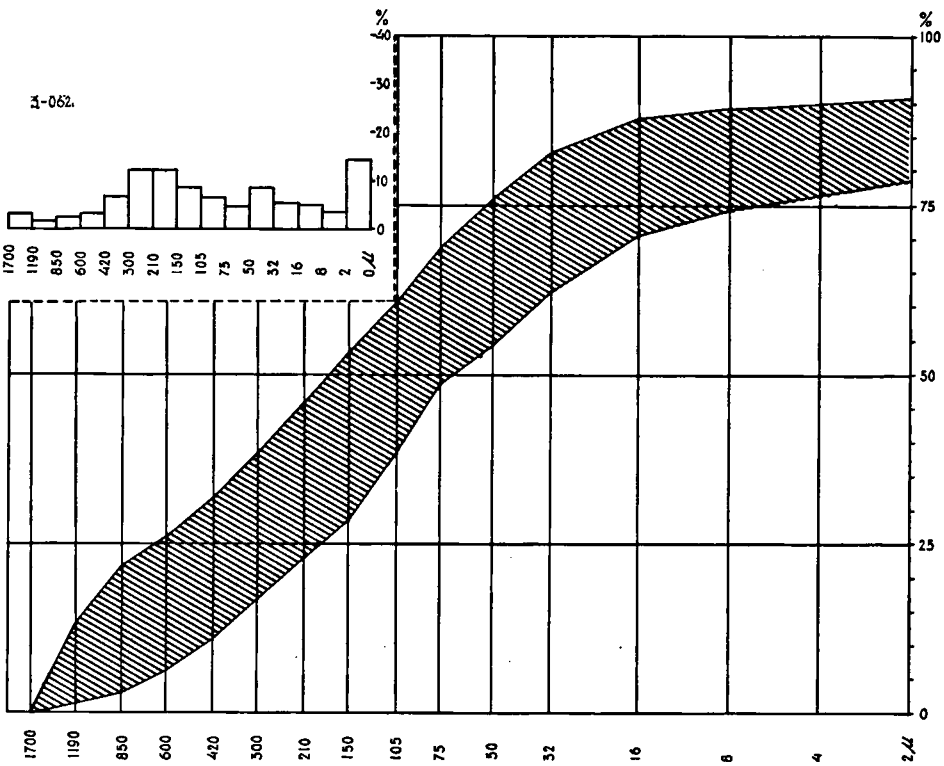

Fig. 13. Zone diagram of size frequency distribution of the silty sand group of sediments in Vega de Riacos facies.

The zone diagram of fig. 13, of the silty fine sand group, has its steep part in the fine sand size fractions, indicating a rather high fine sand size content. But the curves also show the presence of a quantity of silt and clay size particles. Clearly the sediments are of a mixed type. Comparing them with the diagram of calculated mixtures modified after Doeglas (fig. 10), they appear to be situated between his curves C and D. This is due to a relatively high percentage of fine materials, deposited either on floodplain, where it can be caught by vegetation, or in a shallow lake or laguna. The presence of conglomeratic beds and coarse sandstones, frequently alternating with the finer deposits may probably be more due to river deposition alone.

The following statistical values could be determined (table VII). *Md*

TABLE VII.

Some statistical values of the silty sand group in the Vega de Riacos facies.

	Md	Q_3	Q_1	So	$^{10}\log Sk$	q
	in microns					
2-009	90	214	33	2.55	— 0.06	65.5
2-018	96	215	10	4.63	— 0.63	71.7
2-022	112	236	40	2.43	— 0.11	57.6
2-024	120	310	8.4	6.08	— 0.74	69.8
2-039	70	190	12	3.99	— 0.33	48.5
2-044	85	1120	7.2	12.61	+ 0.05	53.7
2-048	72	172	8.8	4.44	— 0.54	60.8
2-049	140	610	13	6.89	— 0.40	60.2
2-050	162	680	51	3.64	+ 0.12	—
2-059	66	203	8.4	4.92	— 0.41	69.8
2-060	170	610	45	3.68	— 0.02	69.1
2-061	87	315	8	6.28	— 0.50	73.0
3-039	71	166	20	2.88	— 0.17	63.0
3-061	100	206	18	3.40	— 0.42	60.5
3-062	108	240	20	3.46	— 0.39	61.1
3-063	124	308	32	3.08	— 0.19	64.2

varies between 170 and 66 microns. *So* shows more extreme values; seven samples of the sixteen are poorly sorted, only two are well sorted, the others are normally sorted. The skewness values are, with two exceptions, negative and rather high; this indicates for nearly all samples a distinct excess of the fine admixtures.

The zone diagram of fig. 14, representing the loam group, has almost the same shape as the diagram of fig. 13 of the silty fine sand group. Both groups are similar, but the zone diagrams occupy a fairly wide range. The median values are lower here, varying between 49 and 20 microns. The high clay percentage causes a poor sorting of the sediment. Half of the deposits even contain more than 25 % of particles $< 2\,\mu$, so that no Q_1 value could be obtained. The average sample 2-043 has the following statistical values: $Md = 28$, $Q_3 = 128$, $Q_1 = 5$ microns; $So = 5.06$, $^{10}\log Sk = -0.08$. The *So*-values of the sediments, so far as they could be determined, vary between 4.04 and 11.08, the $^{10}\log Sk$-values between — 0.08 and — 1.02. All samples appear to be very poorly sorted, and strongly skewed with an excess of the fine components over the coarse.

The curves of the deposits of this loam group, when comparing them with the calculated mixtures presented in fig. 10, lie between Doeglas' D and E curves. The higher clay size content may be a consequence of longer transport, so that the coarse particles lagged behind, and subsequent a deposition on a floodplain, possibly bearing a vegetation which could sieve out the finer particles. Near Alar del Rey coarser material was locally supplied through the valley in which now the present Pisuerga flows.

When comparing our data with those given by Mohr & van Baren (1954), by Bakker (1955, 1957a), and by Bakker & Müller (1957) on river sediments in a recent warm and humid climate (Indonesia, and Surinam, Central Guyana, respectively), it appears that nearly all deposits of the silty and group having the Vega de Riacos facies belong to their bi-phase sediments,

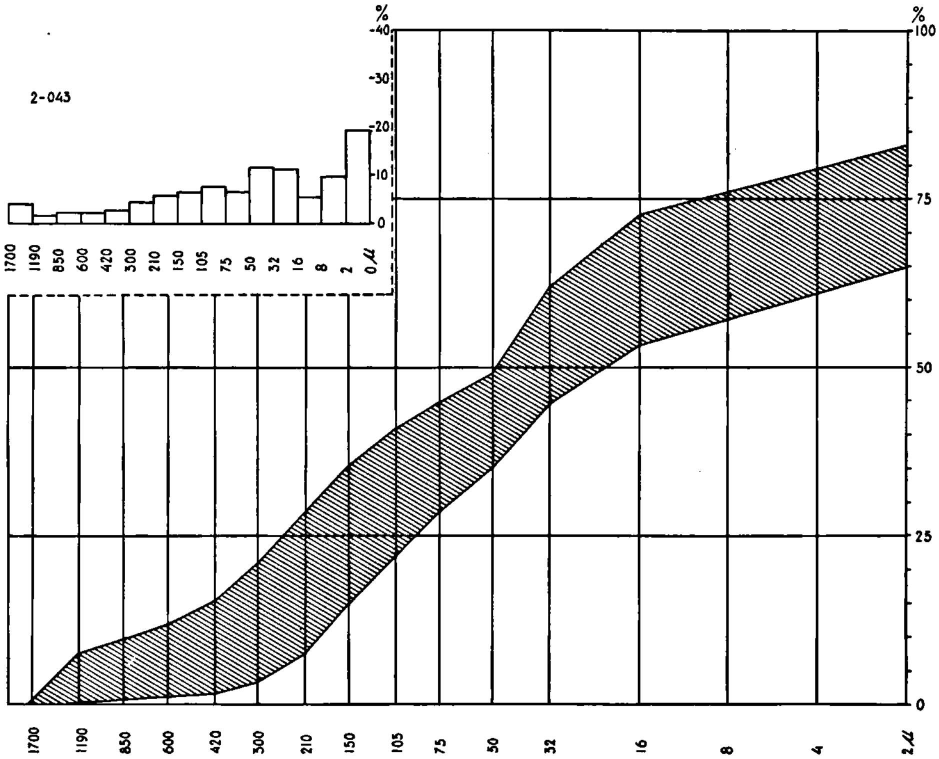

Fig. 14. Zone diagram of size frequency distribution of the loam group of sediments in Vega de Riacos facies.

A-group in the sense of Bakker & Müller. Those of the loam group have a less distinct bi-phasic character. These facts, and also the red colour of the sediments, the shape of the sand grains, and the clay mineral associations are in favour of deposition in a warm and humid climate. Krynine (1950) also assumes such a climate for the origin of red beds, in his work on the well-known Triassic Newark series in the eastern United States.

Another possibility for the genesis of red beds may be that such sediments are residues of red-yellow podzolic weathering, which occurs in a climate with warm and wet summers only (Krebs & Tedrow 1958).

It is, however, striking that in many cases the weight percentages in the size classes 50-32 and 32-16 μ are relatively high. This may be due to a later supply of some fine material by wind into the red beds. It could have occurred in a more arid climate which prevailed during the deposition of the somewhat younger sediments having the Carrión de los Condes facies (see p. 83). Possibly a certain amount of this silty (loess like) material consisted of cemented clay size particles which disintegrated again during laboratory treatment, causing a lower silt percentage and a higher clay percentage (Bakker, personal communication).

The *q*-values of the bi-phasic sediments in the Surinam rivers are high (72—98, most frequently 78—86). Marine deposits show values of about 67, whereas brackish water deposits have very low *q*-values (van Andel & Postma 1954, Wiggers 1955, Bakker 1957a). The *q*-values of our red beds vary from 54 to 80, most frequently from 60 to 75. In how far these values may be attributed to a saline depositional environment, or to a decrease by diagenesis, the sediments having a Miocene age, cannot be proved. If, however, the sediments have undergone a supply of some silty material by wind action, the *q*-values are not representative, and have to be considered with due reserve.

Carrión de los Condes facies

As has been described in chapter III the deposits in this facies consist of all types of clastic sediments known, ranging from conglomerates to clays. The colour generally is yellowish-brown, more rarely reddish-brown. The yellow colour is caused by limonite.

All previous investigators consider them to be fluviatile sediments deposited by braiding rivers, sometimes interrupted by temporary lakes. Comparisons have been made by some authors with the present Laguna de la Nava, W of Palencia town, a temporary lake which in summer is dry and is then covered by a salt crust.

In the investigated area conglomerates are very rare, and equally, real clays. The deposits have been plotted in the triangle diagrams indicated by the numbers 3 in the various figures. Most sediments are not consolidated and so have been presented in a Shepard-diagram. The great extension of the deposits in this facies in the investigated area obliged us to take a great number of samples, in order to obtain a good insight into the changes of the sediments from the mountains towards the basin centre. They have been divided into five areas, presented in two diagrams (3abc and 3de, fig. 8). The areas a, b and c contain outcrops of considerable vertical dimensions, so that samples could be taken at different levels; in the flatter d and e areas (the campiña and páramo regions, at a greater distance from the mountains) the samples belong almost entirely to one level.

In the triangle diagrams two groups of sediments can be distinguished. One lies in the loam segment at the upper right side indicating the presence of only a small content of sand particles. The other is situated chiefly in the silty clay segment. In both diagrams the same two groups are apparent.

The loam group in the 3abc area and that in the 3de area each have been presented as a zone diagram of cumulative curves, both plotted in figure 15. The same was done for the silty clay group (fig. 16), and for each an average histogram is given.

The curves of the loam group (fig. 15) all lie between the D and E types of fig. 10, which means that only fine material was present. The sediments are only a little finer than those of the zone diagram presented in fig. 14 — Vega de Riacos facies. The histograms of the average samples, 3-021 (pure clayey loam) from the 3c-region and 4-050 (clayey loam) from the 3d-region, still show a certain bi-phasic character. The clay size content becomes higher (20—30 %), approaching the values of the B-group of Bakker & Müller.

The diagram in fig. 16, shows the sediments of the silty clay group. The average samples 4-024 (silty clay) and 4-095 (very clayey loam) show a more normal distribution. They may be compared with the C-types of Bakker & Müller, although their clay size content often does not exceed 50 %.

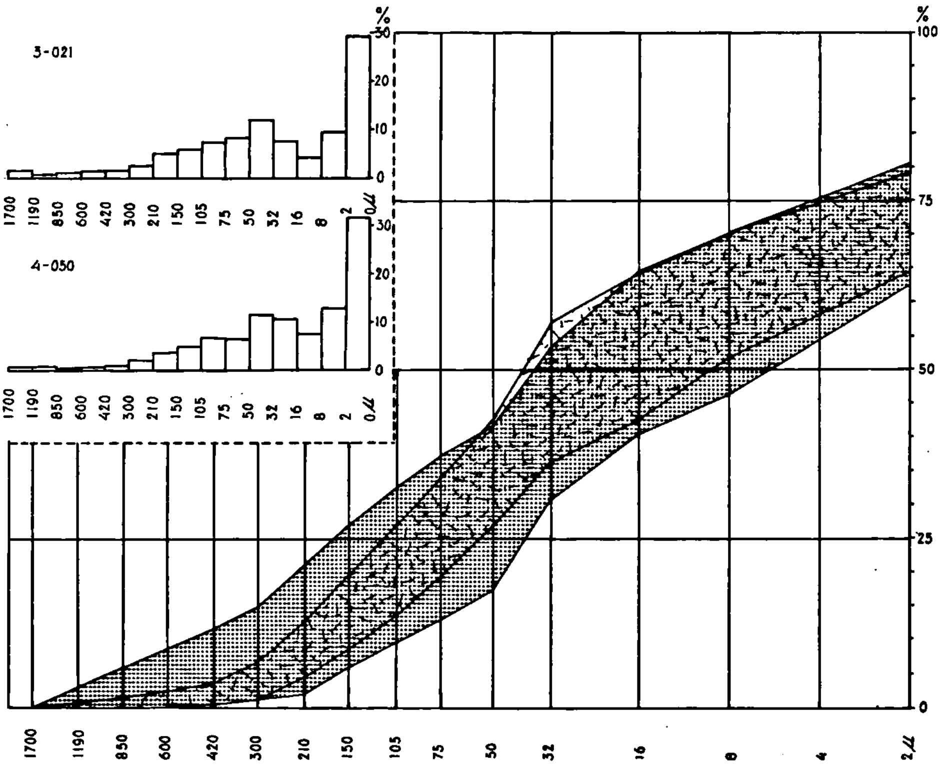

Fig. 15. Zone diagrams of size frequency distribution of the loam groups of sediments in Carrión de los Condes facies.

In Surinam these sediments occur near the shore, in the Duero basin they might represent for a part lake or laguna deposits. Towards the basin centre the river slopes must have become insignificant, causing a very low velocity of the current and the development of shallow lakes and lagunas.

The shapes of the curves show a poor sorting. The majority of the samples having the Carrión de los Condes facies contain a clay size content of more than 25 %. The few samples of which a *So*-value could be determined are all poorly sorted ($So > 4.5$). The $^{10}\log Sk$-values vary between — 0.10 and — 0.50, so they are strongly asymmetrical towards the fine particle sizes. pH-values vary between 7.5 and 8.8; accordingly nearly all deposits contain fine grained calcite.

In the northern outcrops, especially in the 3ab-regions, the upper layers contain a considerable amount of small limestone pieces. They are rounded fragments of crusts caused by evaporating groundwater. We may remind that in the S of the investigated area gypsum was precipitated. So the sediments presenting the Carrión de los Condes facies must have undergone an arid climate during and after their deposition.

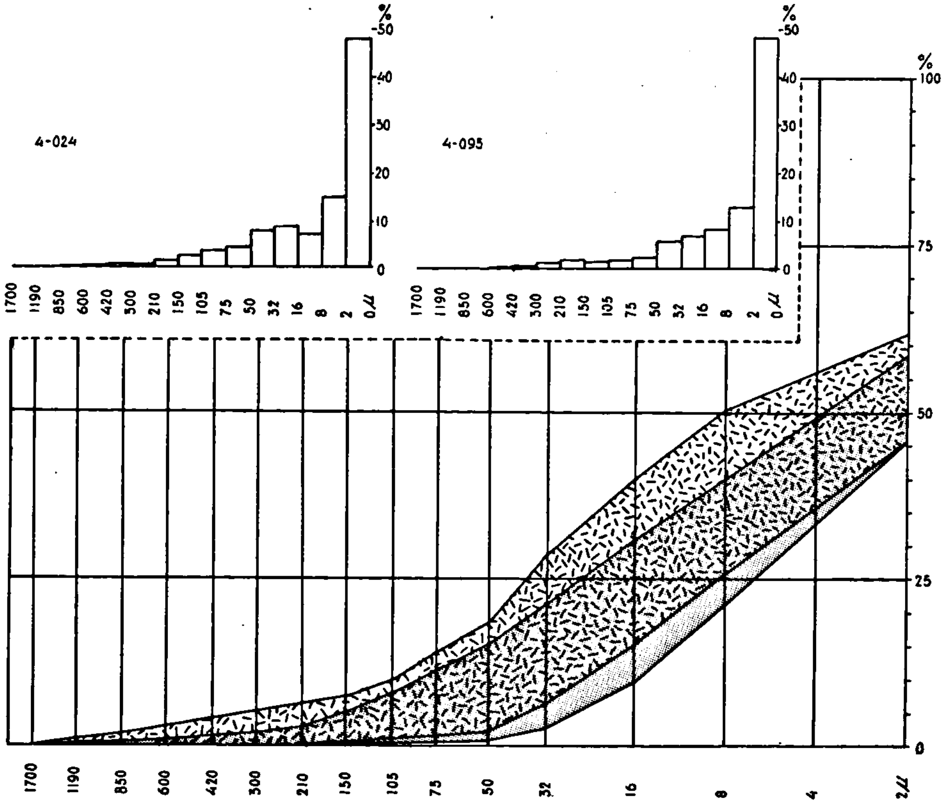

Fig. 16. Zone diagrams of size frequency distribution of the silty clay groups of sediments in Carrión de los Condes facies.

Another argument in favour of this opinion may be concluded from the relatively high weight percentages in the size classes 50-32 and 32-16 microns. At this time certainly a supply by wind may have occurred, causing an increase of particles in the coarse silt size fractions. The q-values (most frequently 50—70) of the yellow deposits in this facies have also to be considered, therefore, with due reserve.

The sediments of the Carrión de los Condes facies thus have a fluviatile and partly a lacustrine origin under a climate with a strong evaporation, and some wind action.

Osornillo-complex. — The typical variation of sediments, as described by San Miguel de la Cámara, was only found in an arroyo near Osornillo, already mentioned in chapter III. Photo XIII shows a part of this outcrop of Osornillo, fig. 17 is a sketch indicating the sampling localities of some typical sediments. The beds rapidly alternate, conglomerates lying next to clayey sands, coarse sands next to bi-phase sediments. Cross-lamination is conspicuous. Locally small pieces of lime point to crust formation, caused by evaporation. The whole complex gives the impression of being a river delta deposit in a lake.

Foto XIII. Some layers of the Osornillo outcrop.

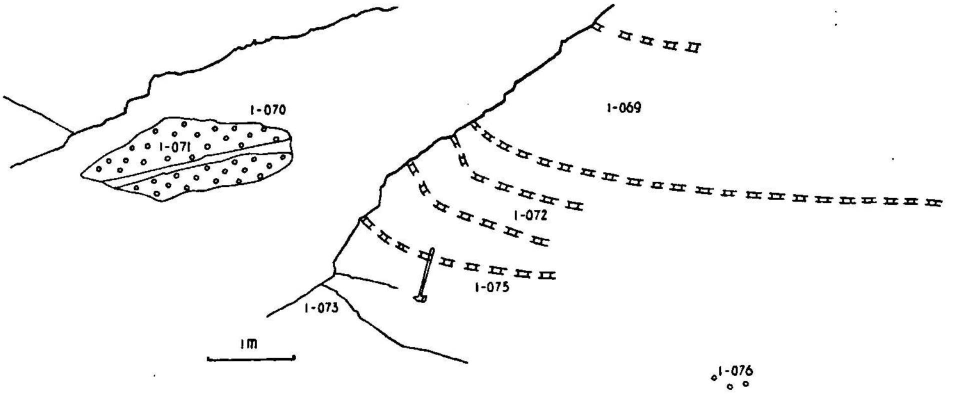

Fig. 17. Sketch of the outcrop of Osornillo, indicating some sampling localities.

Fig. 18 represents the cumulative curves of the Osornillo-samples, without considering the coarse fractions (> 2 mm) of both conglomerates. Compared with the calculated mixtures of fig. 10, it is evident that all deposits of the Osornillo-complex, having a considerable amount of fine suspended

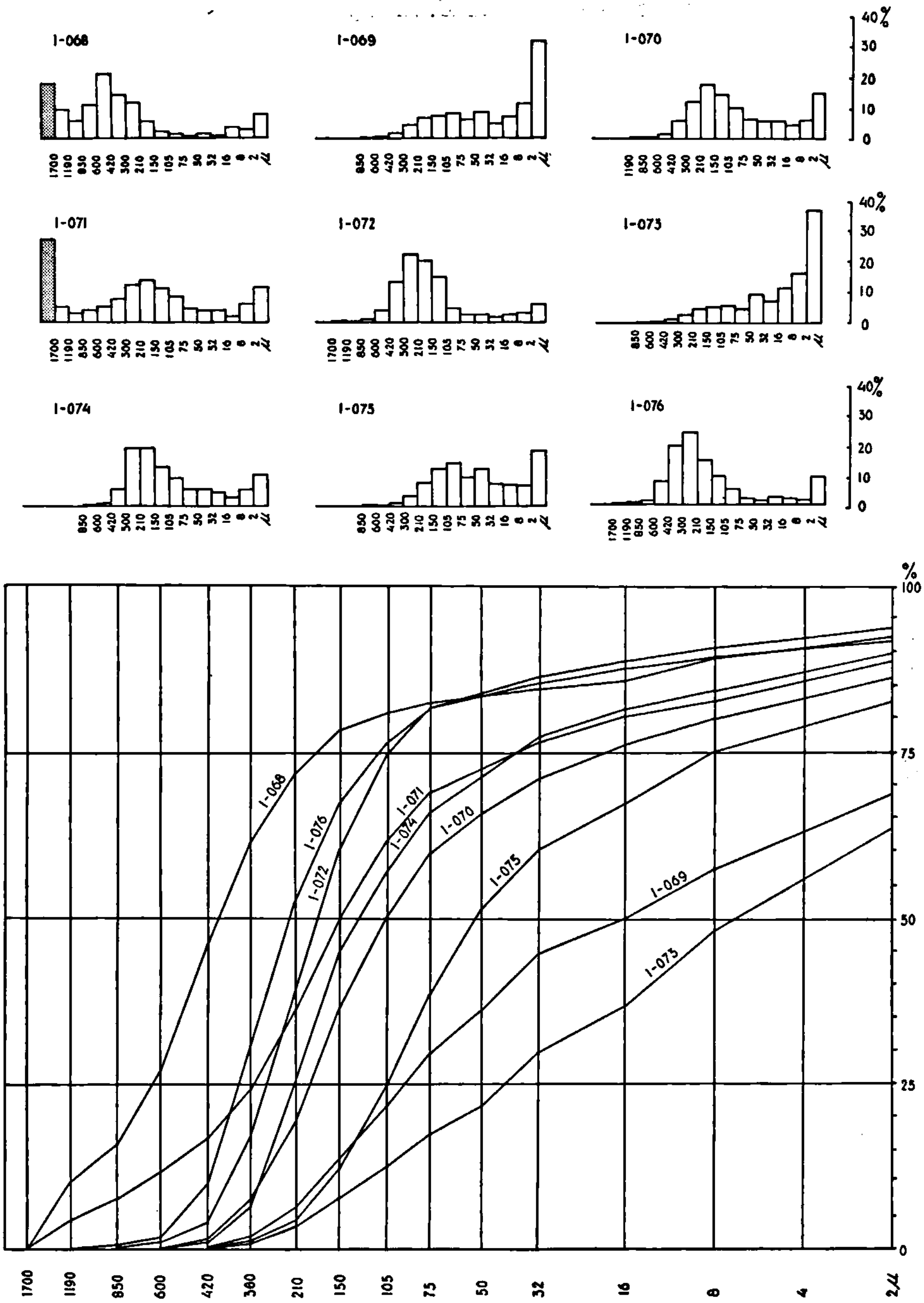

Fig. 18. Size frequency distributions of some sediments from the Osornillo-complex.

material, lie between the curves C and E. The curves of samples 1-068, 1-072 and 1-076 show a perfect sorting (see data in table VIII), but curves 1-069 and 1-073 show a poor sorting. The other delta deposits (samples 1-070, 1-071, 1-074 and 1-075) are well sorted and with negative asymmetry of the curves.

Among the histograms there are some bi-phase sediments, which a distinct second maximum in the sand fraction.

A striking feature among these sediments is the conglomerate lense from which came sample 1-071. It consists of a weakly cemented fine gravel (maximum size 16 mm) with a black to dark purple colour. This colour is caused by a determinable manganese content in the cement, which is concentrated in rather thin coatings around the grains (cement content 14 %). Also in fine conglomerates and coarse sandstones of some other sites within the Carrión de los Condes facies, a certain manganese colouring was found.

Other rare deposits in the Osornillo complex are the "pure", fairly coarse to medium sands. These very loose sands show many small holes, made by wasps which built their nests only in these sands. This type of sand has only been found at one other site, outside the Osornillo-complex.

River deposits of this type, as outcropping in the arroyo of Osornillo, have not been found elsewhere in the investigated area, but there may be some more, hidden by other deposits.

Relea and Zorita facies

The sediments in Relea facies cannot be clearly distinguished in the field from those in Carrión de los Condes facies. The distinction between the latter and this Relea facies was made only on paleontological grounds. They should, therefore, not have different names, the facies being the same. But for the sake of convenience the two names, initially adopted, have been maintained. Some investigators tried to make a distinction between the Vindobonian sediments having the Carrión de los Condes facies and the Pontian sediments having the Relea facies. Ciry (1939) asserts that the upper, or Pontian layers are more often red coloured and contain more sand. Indeed, the lower beds generally show a yellow colour, but in the upper beds the red coloured layers, although present in a great number, do not predominate.

Only the Zorita facies, found W of the river Pisuerga, between Alar del Rey and Herrera de Pisuerga, obviously differs both from the Carrión de los Condes facies and from the Relea facies. A conspicuous feature are the red to pink and white-coloured beds. They lie upon the deeply red-coloured strata in the Vega de Riacos facies. But laterally the sediments presenting this Zorita facies pass into those presenting the Relea facies. At a distance of hardly 7 kilometres W from the Pisuerga valley, where the valley slopes of the Rio Boedo begin, the more calcareous, white layers are replaced by the less calcareous, yellow layers, having the Relea facies. These two facies nearly always are discussed together, considering the Zorita facies as a local aberrant form of the Relea facies.

Coarse sediments having these facies were rarely found, even more rarely than in the Carrión de los Condes facies. The few samples found have been plotted in triangle diagram 4/6 of fig. 6. It appears that the calcareous sandstones and sandy marlstones lie in the lower parts of the respective segments, indicating a rather low percentage of lime.

TABLE VIII.

Analytical data of some sediments of the outcrop at Osornillo.

	name	> 2 mm	2000—50 μ	50—2 μ	< 2 μ	Md	Q_3	Q_1	So	$^{10}\log Sk$	q
						in microns					
1-068	conglomerate	18.1 %	68.0 %	7.6 %	6.3 %	265	620	181	1.85	+ 0.20	53.9
1-069	loam	—	35.8	32.3	31.9	15	—	—	—	—	63.3
1-070	clayey fine sand..............	—	65.1	20.7	14.2	102	181	16.5	3.31	— 0.53	57.5
1-071	conglomerate	26.6	53.3	11.7	8.4	144	285	38	2.73	— 0.28	58.5
1-072	medium to fine sand.........	—	83.5	10.4	6.1	173	253	100	1.59	— 0.07	51.7
1-073	clayey loam	—	21.3	42.1	36.6	6.7	—	—	—	—	57.7
1-074	clayey medium to fine sand	—	70.7	18.8	10.5	128	212	36	2.43	— 0.34	55.5
1-075	clayey fine sand..............	—	47.1	34.8	18.1	33	100	7.8	3.58	— 0.15	53.9
1-076	medium sand	—	83.1	8.0	8.9	218	310	108	1.69	— 0.15	70.5

The fine-grained sediments plotted in Shepard diagram 4/6 (fig. 8), also clearly can be divided into two groups, one in the loam segment, the other in the silty clay segment. However, these groups occupy a smaller range than those in the Carrión de los Condes facies. Especially in the Zorita facies, but also in some outcrops of the deposits in Relea facies, the white and grey coloured sediments have a high lime content. They are scattered over the whole marl range of the 4/6 diagram of fig. 7. Where these marls occur, the underlying sandy and clayey deposits have often been strongly consolidated.

The deposits of the loam group are represented as zone diagram in fig. 19. The average sample 1-014 (pure clayey loam) originates from

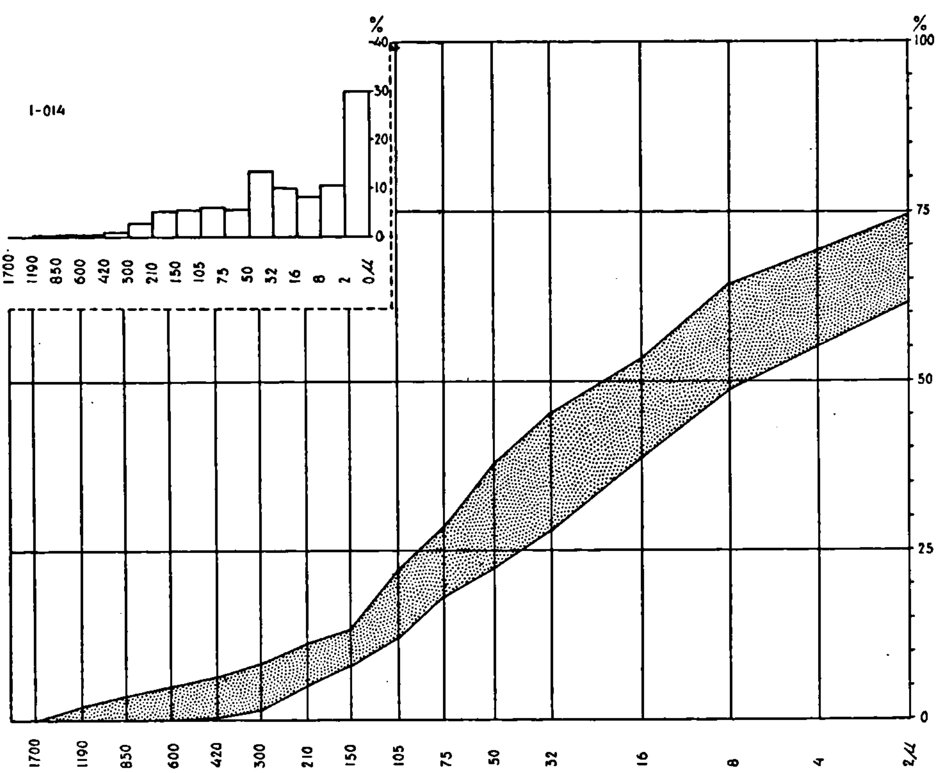

Fig. 19. Zone diagram of size frequency distribution of the loam group of sediments in Relea and Zorita facies.

the transition zone of the Relea to the Zorita facies. The zone diagram lies between the calculated D and E curves of fig. 10, in a somewhat finer range than the loam group diagram in the Carrión de los Condes facies (fig. 15). A considerable amount of fine suspended material was present also here. The general shape of the curves is so similar to that of the sediments in the Carrión de los Condes facies, that a similar depositional environment may be supposed. The average histogram again shows a sediment belonging to the B-group of Bakker & Müller, and the lower layers show also some aeolian influence. The *Md*-values are equally low, and the Q_1-values could not be determined either. These sediments are poorly sorted, only one sediment of the whole group contains exactly 25 % of clay size particles, it has $So = 6.23$.

Fig. 20, which presents the silty clay group, shows a slightly coarser range than the silty clay group in the Carrión de los Condes facies. They appear to be nearly E deposits, as compared with fig. 10. The *Md*-values

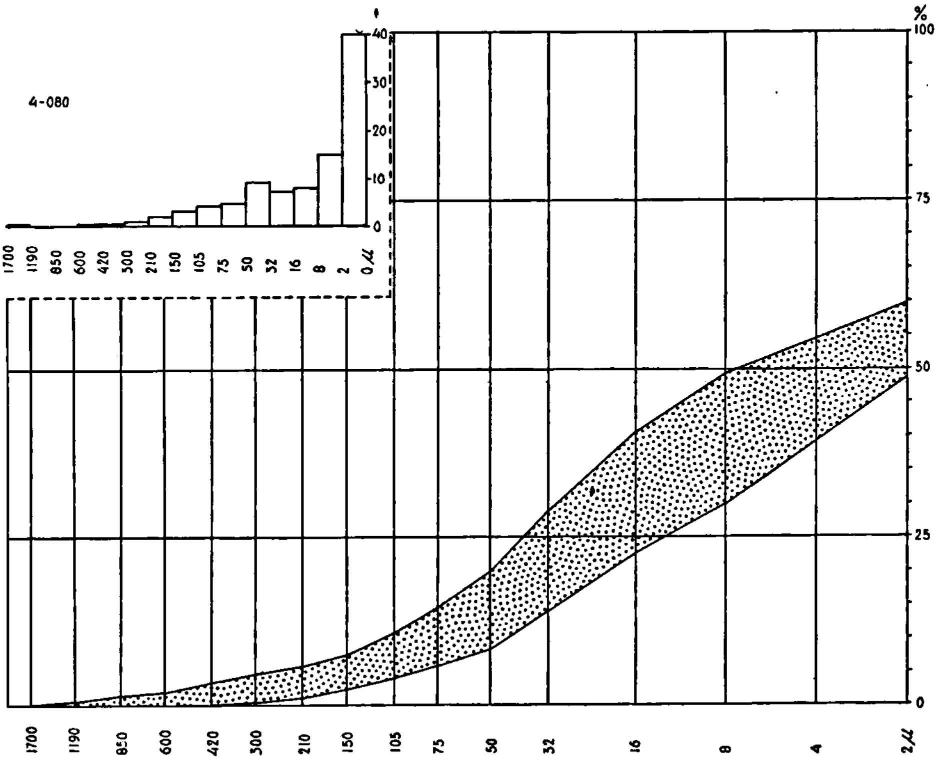

Fig. 20. Zone diagram of size frequency distribution of the silty clay group of sediments in Relea and Zorita facies.

lie near 2 microns. The average sample 4-080 (silty clay) originates from the most southern outcrop of the Relea facies. It is still a sediment, belonging to the B-group, though the clay size content lies nearly at the upper limit of this group.

The most frequent *q*-values (57-74) are somewhat higher than those of the Carrión de los Condes facies. Also a number of values > 74 (even up to 91) can be found. The younger the layers, the higher are their *q*-values. Especially in the higher beds these *q*-values may have some importance, possibly indicating a deposition in a true fluviatile environment. The *q*-values in the lower beds are not significant. These beds contain thin lime crusts, indicating that the arid climate, which also reigned during the deposition of the upper layers in the Carrión de los Condes facies, still prevailed.

The insoluble residues of the white and grey marly deposits have not been represented in size frequency curves. Their limited occurrence in the

Zorita facies, where the sediments are white, and in a small region of the Relea facies, where the sediments are more greyish, lead to the conclusion, that these sediments are remainders of lake deposits. A supply of much lime in the region of the Zorita facies was easy to understand, the Mesozoic limestones and marls being exposed only at a short distance N of the Zorita facies area. ...

When comparing the data given for the deposits in Carrión de los Condes facies and in Relea facies, it may be concluded that both must have the same origin, with fluviatile environments predominating over lacustrine, under the same, or nearly the same climate. Red layers may indicate temporary fluctuations of this climate. Obviously the various beds are too thick to be attributed to single seasonal variations.

The supposition of Ciry that the sediments in the Relea facies generally contain more sand, is not confirmed by the grain size analyses. The only difference consists in a greater number of red layers in the Relea facies. A clear separation of both facies in the outcrops near Saldaña cannot be carried through. Only the sediments in the Zorita facies can be clearly distinguished from the underlying deposits in the Vega de Riacos facies. The separating bedding plane, possibly a disconformity here, when projected into the Relea facies region, gives the separation between the Relea and Carrión de los Condes facies. In this region, however, sedimentation went on without change from Vindobonian into Pontian times.

Páramos facies

The lime and gypsum bearing deposits of this facies represent the sediments of the basin centre. They only occur in the eastern part of the Duero basin, due to the supply of calcareous matter from the Mesozoic limestones of the Cordillera Iberica. The western half of the central basin was supplied from other source areas with less limestones, and consequently the sediments contain less lime. The western boundary of the limestone páramos, showing some small outliers, passes through the investigated area (see fig. 3, page). The sediments in this Páramos facies overlie the yellow deposits in the Carrión de los Condes facies (region 3e). An average section through an outcrop (after Dantín Cereceda) has already been given in fig. 5 (page).

The marly sediments have a greyish colour, in which the great gypsum crystals sparkle in the sunlight. The limestones, which are intercalated between these marls, are white, whereas the limestone lying on top, called Páramos-limestones, are more bluish to yellowish. The outcrops along the valley slopes with their dominating whitish colour are a typical feature of the Castilian basin landscape.

Gypsiferous marls only develop under semi-arid climatic conditions, with considerable evaporation, though a certain drainage must have existed, because of the absence of halite deposits. All samples gave negative reaction to the halite determination test.

The marls are often unconsolidated. The determinations plotted in diagram 5 of fig. 7 are based only on carbonate, sand, and silt/clay content. When gypsum is present, this has been mentioned separately. These gypsum-bearing beds vary from marly limestones to clayey marls. Gypsum occurs either as crystals (called algez), or as compact beds (called jalón), mostly intercalated between marls containing only very finely granular gypsum. This is the gypsum content, that has been determined. The crystals sometimes are very great, with a length of 30 to 40 cm, showing the typical arrowhead twin-form (Spanish: *pata de cabra*). Gypsum is worked in a number of quarries.

The grain sizes of the insoluble mineral components (together calculated as 100 %) of six marls and clayey marls are presented as cumulative curves (fig. 21). They occupy only the lower right angle of the diagram, which alone therefore has been reproduced. The percentage of grains > 75 μ, when present, is always very small. The clay size content varies between 60 and 85 %. Because in most samples the sand size fraction is totally absent, the

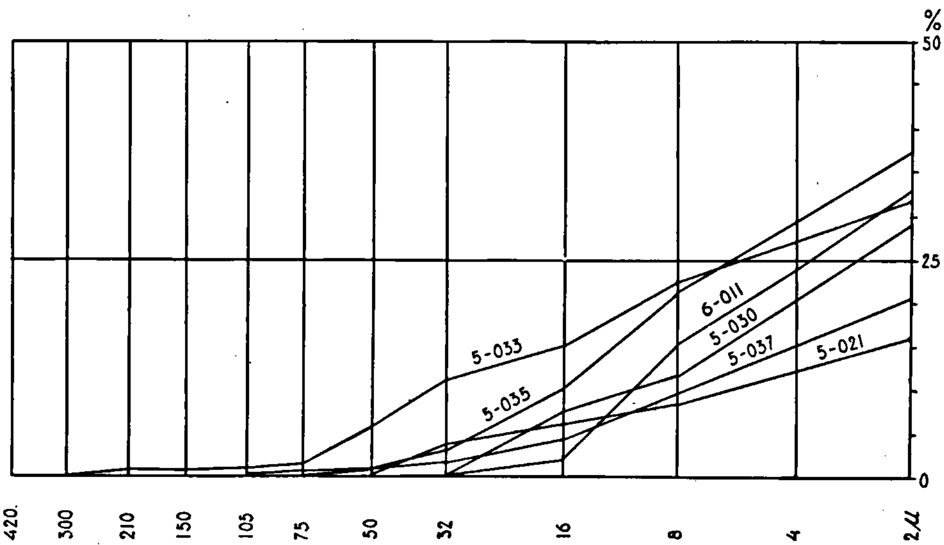

Fig. 21. Size frequency distributions of the non-soluble mineral components of some marls in Páramos facies.

points lie on the 0 % sand line in the triangle-diagram. These sediments are clearly lake or laguna deposits. Lying below the E-curve of calculated mixtures (fig. 10), they represent deposits in stagnant, or perhaps sometimes very slowly flowing water.

The limestone on top of the exposures, the so-called Páramos-limestones, are always pure limestones, containing 5 % or less non-carbonate particles, which are mainly quartz crystals grown during diagenesis. The limestones are gypsum-free. The limey components are often rather coarse-grained crystals. The soils of this Páramos-limestone have a greyish-brown, only rarely reddish-brown colour. At the surface, where the inhabitants have some fields, they can be wholly carbonate-free. The more carbonate matter has remained in the soil, the less reddish is the colour.

At some sites towards the basin centre these Páramos-limestones are underlain by other limestones, called argillaceous limestone by Ed. Hernández-Pacheco (1915). They belong to the marly limestones and even limey marlstones (without gypsum) figured in the triangle 5 (fig. 7). The "unweathered" argillaceous limestone is very soft, and of greenish to greyish colour, but often with red spots and stripes. This type of limestone represents a fairly weathered sediment, which during a certain time must have been exposed at the surface, before the real Páramos-limestone was deposited. Its soils are always deeply red-coloured. Several *páramos,* where the real Páramos-limestone is missing, show, therefore a red cover on the white and grey underlying beds.

Evaporites. — The evaporite-containing deposits in the Páramos facies thus only consist of calcite and gypsum, all other salts being absent. The deposited gypsum is rather pure. The percentage of $CaSO_4 . 2 H_2O$ as calculated varies between 94 and 98 %, the remainder being anhydrite. Gypsum is formed (at 30°C) at a salinity of 3.35 times that of normal sea water (Posnjak 1938, 1940). Direct precipitation of anhydrite only occurs at a salinity of 4.8 times. As there is some anhydrite, the salinity may have occasionally increased. Moreover, some anhydrite may have changed into gypsum later.

The initial salinity in the terrestrial environment is not known. Water analyses of present ground water pumped up from wells in the yellow and red layers, far away from the gypseous deposits, show that the amount of carbonates and sulfates vastly exceeds the amount of chlorides (see memoirs of the geological maps 1:50 000 of Spain, sheets 133 and 235). This may have been almost the same in Tertiary times. In the case of evaporation mainly carbonates, and later sulfates, will precipitate. If some gypsum has been formed by reaction of sulfate-bearing water with the already precipitated lime, we do not know. Later, during diagenesis, the fine-grained gypsum crystals grew to the very great crystals at present found in the deposits in the Páramos facies.

Páramo de la Miranda, a type locality. — One of the best outcrops in the investigated area is the Páramo de la Miranda, N of the town of Palencia, forming the eastern valley slope of the Rio Carrión (photo XII, representing its E flank). Already Ed. Hernández-Pacheco (1915) clearly describes the section in his monograph, mentioned several times before. This outcrop, therefore, has been chosen for more detailed sampling. Fig. 22 presents first the profile drawn by Hernández-Pacheco, to which the results of the grain size analyses of the various samples have been added, together with their proper designations according to the triangle-diagram.

Sample 6-001, lying on top, is the soil of the Páramos-limestone, forming a thin cover of about 30 cm. The carbonate content is small, the colour therefore reddish. 6-002 is the real Páramos-limestone and 6-003 the argillaceous limestone *(caliza arcillosa)*, which has a greenish colour here. From the base of this soft limestone upward the degree of cementation rapidly increases.

The marly, gypsum-bearing beds are dominantly limey marls (6-004, 6-005, 6-006 and 6-013), alternating with some marly limestones (6-007 and 6-012) and marls (6-011). Within one of the gypsum layers nearly black-coloured crystals occur. They contain decomposed remains of organic matter, smelling of H_2S.

In the middle of the marly beds occur two yellow clayey layers, each with a thickness of 4 m, and a white limestone of 2 m between them. Both samples (6-008 and 6-010) are yellow clayey silts, the upper containing some infiltrated gypsum. The white bed between them, called by Hernández-Pacheco a marl, but in reality a pure limestone (sample 6-009), does not contain gypsum. These three beds are only present in the western outcrops in the Páramos facies. They clearly represent an invasion of clastic sediments during a temporary increase of water supply, through which the salt concentration

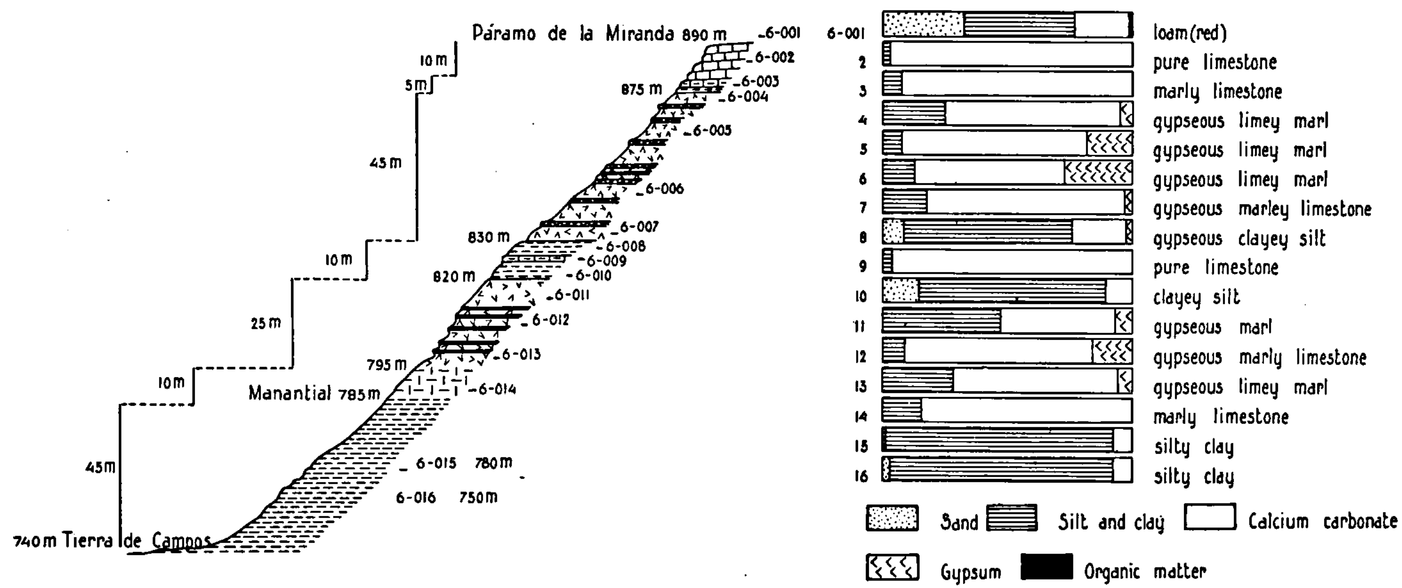

Fig. 22. Section through the Páramo de la Miranda (after Ed. Hernández-Pacheco), with the results of the grain size analyses of the various samples.

in the lake or laguna has decreased. This decreasing salinity is shown also by the lower *q*-values of the yellow beds, namely 39 and 47. Slightly saline and brackish environments generally have low q-values (20—50). These values, in this case, may be considered significant, the deposits showing no evidence of wind-borne material. In the northern and eastern outcrops of the páramo area, the yellow layers are absent. Only in the N are they replaced by white, rather pure, limestones, without gypsum.

Finally there are the yellow "clays of the Tierra de Campos", lying below the marly beds. These are silty clays with a very small sand size content, representing the Carrión de los Condes facies (samples 6-015 and 6-016). Upward they become slightly richer in lime, and between 785 and 795 m they have passed into a marly limestone (6-014), which still does not contain any gypsum. The sandy layers, between the clays and marls, in which 1 km southward the fossil mammals of the Cerro del Otero of Palencia have been found, are missing here.

Final remarks. — The yellow beds could thus be dated as Middle to Late Vindobonian, the Páramos-limestones as Pontian. The development of gypseous marls indicates a warmer and drier climate, in which evaporation was relatively high. A correlation between this region and that in the N, also with uninterrupted sedimentation (Carrión de los Condes facies into Relea facies) has been made in chapter X.

Quaternary deposits

The Pleistocene sediments in the investigated area are the mountain foot debris in the N, and the river terraces occurring along the present rivers and occasionally in now nearly dry valleys.

The sediments of the pediment debris are coarse, and will be described in chapter VI. Their fine components do not have a character of their own, but show a mixing with the underlying deposits.

Only the river terrace sediments have been analyzed on grain size, after sieving out of all components coarser than 2 mm. Because the transporting medium is known in the case of terrace deposits, and need not be derived from the analysis, the presentation of the results serves only as a confirmation. The curves give a characteristic aspect of the deposits. Fig. 9 presents the triangle-diagrams of the various terrace sediments, classed according to the rivers by which they were deposited. The majority of the deposite are silty sands. These are the unmixed terrace sediments with a grey colour, containing a lot of pebbles. Their pH-values (5.5—7.0) are lower than those of the Tertiary sediments. Therefore carbonates are absent. Only the silty sands, being the most abundant real terrace deposits, are presented in cumulative curves. Table IX gives their statistical values, which could always be determined.

Nearly all other sediments, especially those with a lower sand size content, are deposits mixed with the underlying Tertiary layers, chiefly those having the Carrión de los Condes facies. Often their colour is more yellowish and their pebble content is low. The pH is higher (up to 8.0), and carbonates in small amounts are mostly present. In the páramo region the terrace deposits have been strongly cemented by infiltration of lime, derived from the adjacent marls and limestones in the Páramos facies. The non-calcareous mineral components, after sieving out all sizes > 2 mm, are coarse

TABLE IX.

Some statistical values of the unmixed terrace samples.

	Md	Q_3	Q_1	So	$^{10}\log Sk$
	in microns				
Rios Boedo and Valdavia terraces.					
1-001	67	152	7.8	4.55	— 0.56
1-002	90	200	19.5	3.20	— 0.32
1-003	70	140	15.5	2.99	— 0.36
1-004	82	181	33	2.34	— 0.05
1-005	79	163	24	2.60	— 0.22
1-006	71	180	19.5	3.04	— 0.22
1-008	81	140	34	2.03	— 0.11
1-009	82	180	32	2.37	— 0.06
1-011	96	190	43	2.11	— 0.05
1-015	157	450	39	3.39	— 0.14
1-016	153	480	44	3.31	— 0.04
1-021	78	180	20	2.99	— 0.22
1-022	76	225	32	2.64	+ 0.10
1-026	96	207	34	2.47	— 0.12
1-034	89	280	8	5.92	— 0.75
1-035	92	272	20	3.68	— 0.19
1-036	54	114	19	2.44	— 0.12
1-039	104	292	34	2.92	— 0.03
1-040	75	292	26	3.35	+ 0.13
1-044	88	220	40	2.35	+ 0.06
3-036	85	160	31	2.27	— 0.16
3-037	80	136	30	2.13	— 0.19
Rio Pisuerga terraces.					
1-050	85	315	34	3.06	+ 0.17
1-051	78	298	22	3.67	+ 0.03
1-052	92	290	16.5	4.20	— 0.24
1-053	52	105	14	2.75	— 0.26
1-055	82	190	32	2.43	— 0.04
1-056	86	500	35	3.78	+ 0.37
1-057	61	170	4.8	5.90	— 0.66
1-058	58	193	20	3.11	+ 0.06
1-059	68	204	18	3.36	— 0.11
1-089	100	193	28	2.62	— 0.26
Rio Carrión terraces.					
1-081	100	212	43	2.20	— 0.03
1-084	73	182	24	2.74	— 0.09
1-085	84	215	14	3.93	— 0.37
1-087	58	98	22	2.11	— 0.18

sands. The extension of the terraces in the investigated area will be treated in chapter VI (Pebble analyses).

Pisuerga terraces. — A zone diagram of the silty sands of the Rio Pisuerga terraces is given in fig. 23. The curves occupy a rather narrow range, except for the coarse sand sizes. The curve zone diagram shows a good sorting of the sediments, except for two samples (see the table) which are poorly sorted.

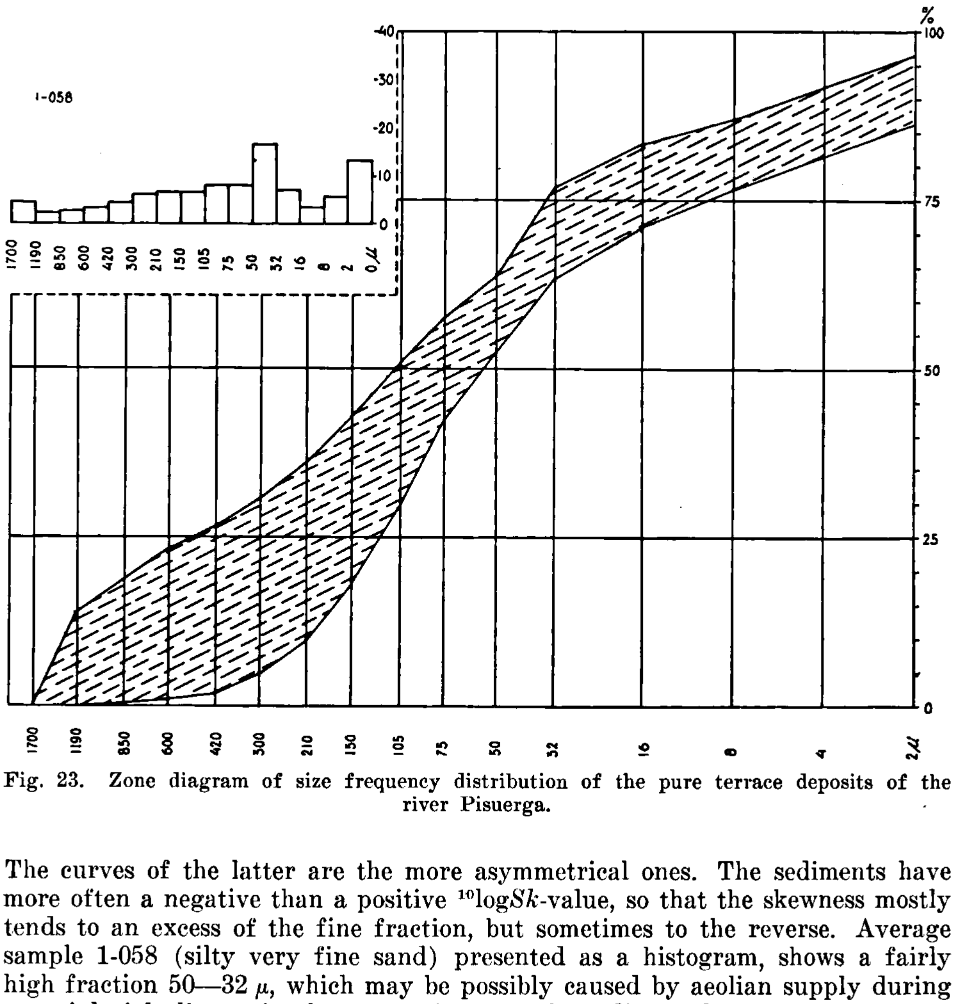

Fig. 23. Zone diagram of size frequency distribution of the pure terrace deposits of the river Pisuerga.

The curves of the latter are the more asymmetrical ones. The sediments have more often a negative than a positive $^{10}\log Sk$-value, so that the skewness mostly tends to an excess of the fine fraction, but sometimes to the reverse. Average sample 1-058 (silty very fine sand) presented as a histogram, shows a fairly high fraction 50—32 μ, which may be possibly caused by aeolian supply during a periglacial climate in the mountain area, the sediment lying near this area.

Boedo and Valdavia terraces. — The terrace deposits of these less important rivers always have been taken together. The reasons why will be mentioned in the next chapter.

Fig. 24 shows the zone diagram of a great number of samples. They occupy a wider range than the Pisuerga terrace deposits. Sorting is good, and skewness is directed towards the finer admixtures. Average sample 1-005 (silty fine sand) shows a bi-phase sediment, which is representative for a floodplain sediment. It may be classed into the A-group of Bakker & Müller.

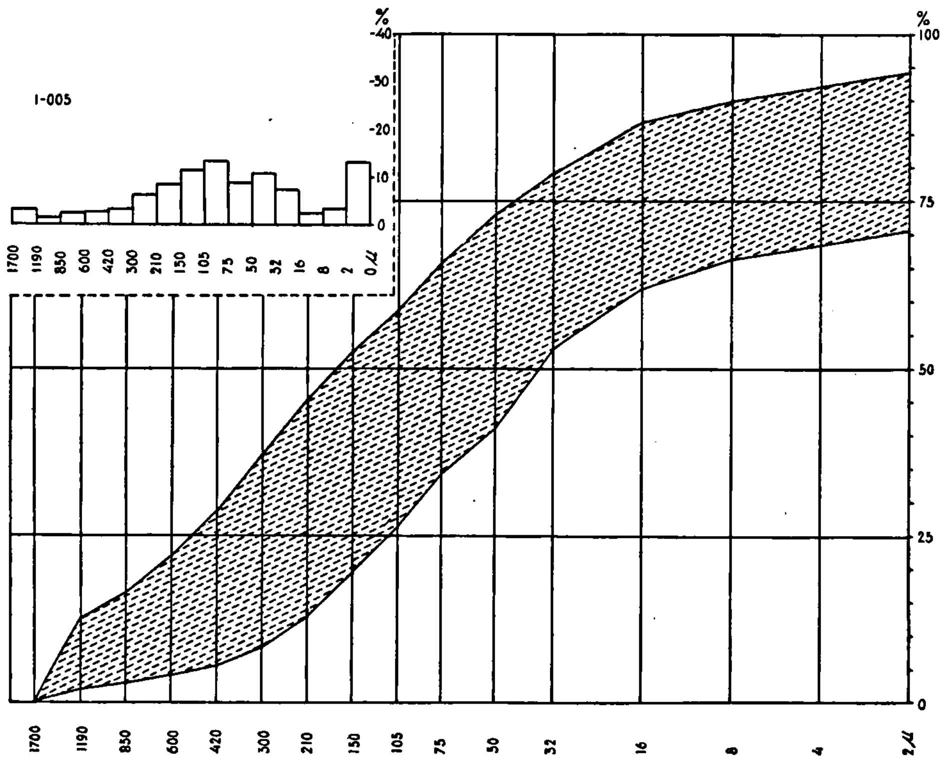

Fig. 24. Zone diagram of size frequency distribution of the pure terrace deposits of the rivers Boedo and Valdavia.

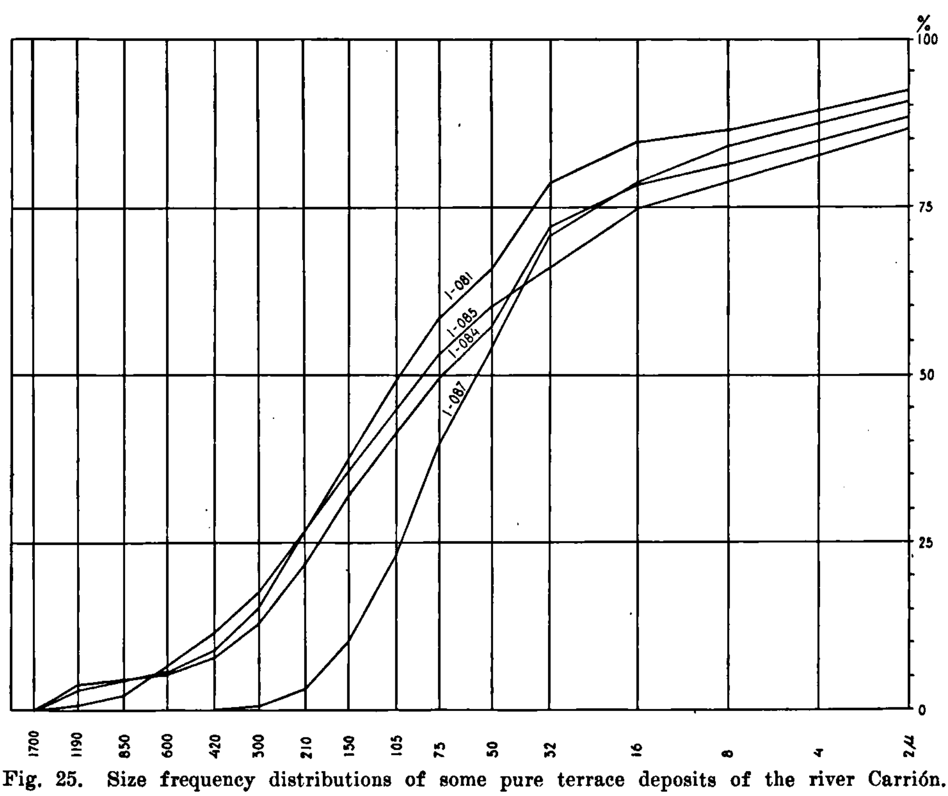

Fig. 25. Size frequency distributions of some pure terrace deposits of the river Carrión.

Carrión terraces. — Only a few samples of the Carrión terraces have been taken. Many of these show mixing with the underlying Tertiary deposits. A zone diagram could not be drawn, but in fig. 25 the cumulative curves of the Carrión silty sands are given. Here also the similarity with the other terrace sediments is striking. All these sediment types appear to have had a fairly large supply of fine suspended materials. As the bottom materials, too, were rather fine-grained, this resulted in fine-grained terrace deposits. From whichever level the sample was taken, the sediment remained the same. Grain size analyses, for this reason, did not provide a means for the distinction of the various terrace levels. For this purpose other analyses were necessary.

CHAPTER VI

COMPOSITION, SHAPE AND ROUNDNESS OF PEBBLES

Gravel composition

In the investigated area two types of gravel occur, (1) a gravel type consisting chiefly of limestone components, and (2) a gravel type consisting chiefly of quartzite components.

The limestone gravel, which has become a conglomerate, is found only in the Cuevas facies. The limestones themselves show many variations in colour. When making the counts we divided them into five groups, but these are only of importance for determining the source rocks, and have not been mentioned in a table.

The gravels consisting mainly of quartzites are found in the remainder of the investigated area. They can be divided into three groups, (a) the gravels, in the Vega de Riacos facies in which they became conglomerates, (b) the pediment-debris, and (c) the gravels of the terrace deposits. Also the quartzites show variations in colour. For the same reason as for the Cuevas facies these variations are of minor importance, and have not been mentioned further.

The other components of the gravels will be mentioned when describing separately the sediments containing pebbles.

Morphometrical gravel analysis

The methods for morphometrical analysis of pebbles, cobbles and boulders, introduced by Wadell (1932), Wentworth (1933), Pettijohn (1936), and Krumbein (1941a, b), and much used in America, are rather intricate and time consuming if compared with the method of Cailleux (summarized in 1956), which is much used in European countries.

The so-called "indices of Cailleux", which were judged upon their merits by Berthois (1950) and by Tricart & Schaeffer (1950), are:

the index of flatness: $\frac{L + l}{2E}$,

the index of dissymmetry: $\frac{AC}{L}$, and

the index of roundness: $\frac{2r}{L}$, (fig. 26).

Not all indices have been adopted without criticism. Poser & Hövermann (1952), for instance, met with difficulties when using the flatness-index. They found that with decreasing l, i. e. increasing flatness, as well as with increasing L, i. e. increasing slenderness, the thickness E remaining constant, the values of the index increase. In this way slender but not flat, and flat but not slender pebbles may get the same index value. And because flatness and slenderness are two different shapes, each subject to its own laws, they divided the Cailleux flatness-index into: (1) flatness $= \frac{l}{E}$, and (2) slenderness $= \frac{L}{l}$. They presented the ratio of these two indices,

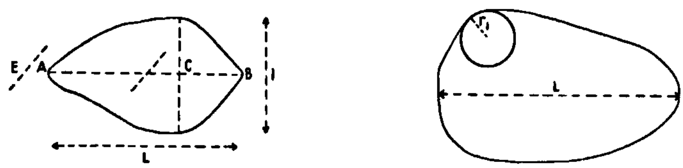

Fig. 26. Pebble parameters used for the morphometrical analyses (after Cailleux).

after calculation of the absolute value of flatness minus slenderness for each pebble, in a difference-diagram for the whole count. Strongly flattened pebbles are seldom slender, and extremely slender pebbles are only rarely flattened. Normal specimens have practically equal flatness and slenderness values.

Some objections have also been made against the dissymetry-index, i. e. $\frac{AC}{L}$, whereby $0{,}5 \leqq \frac{AC}{L} \leqq 1$, or avoiding fractions, written in the form $500 \leqq \frac{1000\,AC}{L} \leqq 1000$. In practice, however, this index appears to be useful (K. Kaiser, 1956), because its deviations never become so great that the interpretation will be inaccurate.

More serious objections have been put forward against the roundness-index, in its form of $\frac{2r}{L}$, whereby $0 \leqq \frac{2r}{L} \leqq 1$, or in its more practical form $0 \leqq \frac{2000\,r}{L} \leqq 1000$. Here a slightly-rounded, spherical pebble can have the same index as a well-rounded, ellipsoidal pebble. Poser & Hövermann propose the use of the whole shape for determining this ratio, but they have to admit that until now the Cailleux index has provided good results, and that their proposal is unpractical. K. Richter (1954, 1955) takes the rounding with the greatest radius also into consideration, but this is often ∞. K. Kaiser (1956) proposed an index in which he considered to a certain degree the shape of the pebble. His roundness-index is $\frac{4r}{(L + l)}$ so that $0 \leqq \frac{2000\,r}{L} \leqq \frac{4000\,r}{L + l} \leqq 1000$. This ratio avoids the need to use an equal index for well-rounded, ellipsoidal, and slightly-rounded, spherical pebbles.

Van Andel, Wiggers & Maarleveld (1954) compared the American and French methods, and also that of Zingg (1935), on samples from marine gravels in the Netherlands. They found that the roundness-indices of Krumbein and Cailleux are closely related, so that nearly $R_c = \pm (R_k)^2$. Although they prefer the American ratios R_k and S (sphericity), which, when determined, give Zingg-values too, they nevertheless admit that the Cailleux-indices are more easy to obtain, and much more in use.

Kuenen (1955, 1956) made experimental studies on the rounding of pebbles by different agents. He proposed to determine $\frac{2r}{l}$, instead of $\frac{2r}{L}$, on experimental grounds. A long ellipsoidal pebble, for instance, will roll around its l-axis, and not around its longest axis, so l has a greater importance than L.

Comparison of some indices

We have compared two samples treated according to the different methods for determining roundness, flatness, and slenderness of the pebbles. Fig. 27 shows the histograms of the values for two types of conglomerates, viz. a limestone conglomerate in the Cuevas facies, and a quartzite conglomerate in the Vega de Riacos facies.

Roundness-indices. The relations between the roundness-indices of Cailleux, Kaiser, and Kuenen respectively, can be written as:

$$0 \leqq \frac{2000\,r}{L} \leqq \frac{4000\,r}{L + l} \leqq \frac{2000\,r}{l} \leqq 1000.$$

It appears that the frequency histograms after Kaiser show a displacement towards the classes with a greater roundness value, and the histograms after Kuenen a still greater displacement. As to the limestone pebbles, the histogram after Cailleux shows a conspicuous double maximum due to the origin of the conglomerates. The histogram after Kuenen shows the same to a smaller degree, but in that after Kaiser the second maximum has sunk below the mean error. The lower maxima in the Kuenen histogram are caused by displacement towards the greater roundness values.

The histograms of the quartzites show more conformity. That of Cailleux has a greater frequency in the less rounded classes. In experiments on rounding (Kuenen) the pebbles pass relatively swiftly through the first roundness class (0—100) only, and take a longer time in obtaining a better roundness. The highest roundness class is only rarely reached, and pebbles belonging to this class are therefore rare. Indeed, we found nearly equal percentages of the most rounded pebbles in all three histograms, (> 700, Cailleux 2 %, Kaiser 2 %, Kuenen 6 %, for the limestone pebbles).

Fully realizing some of the objections put forward by these other investigators against the Cailleux roundness-index, we nevertheless adopted the Cailleux values in our work on pebbles in the investigated area. One of the reasons, which turned the scale, was that in doing so we could compare our results with those obtained by many other investigators during the last years, especially by Tricart and by Soares de Carvalho.

Flatness- and slenderness-indices. — The Cailleux index for flatness $\frac{L + l}{2E}$, and that of Kaiser $\frac{l}{E}$ show in their respective histograms a great conformity. The limestone pebbles are not very flat, and the quartzite pebbles only a little more so. We preferred the flatness-index after Cailleux because of its wide use, so that we could compare our results with those obtained elsewhere.

The slenderness-index $\frac{L}{l}$ after Kaiser, however, considerably deviates from the flatness-indices. As the limestones and the quartzites in the investigated area are not slender at all, a distinction between slenderness-index and flatness-index was immaterial to our purposes.

For the quartzites neither the flatness, nor the slenderness is of great importance for making conclusions on source area, transport, and palaeo-

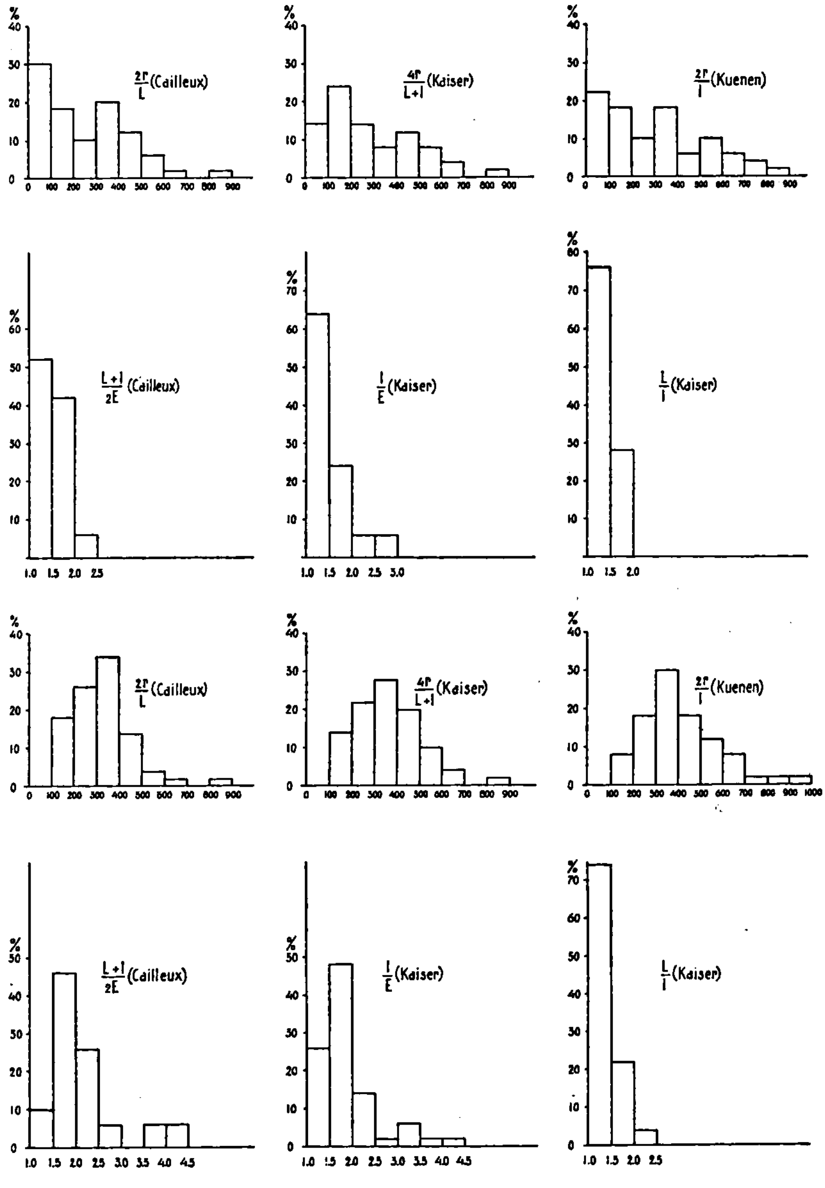

Fig. 27. Comparison of pebble roundness, flatness, and slenderness, calculated according to different methods. (The upper represents the limestone pebbles, the lower the quartzite pebbles.)

climate. The differences obtained by the various calculations are so small that for every kind of sediment one histogram is sufficient, and will be figured when describing the analyses.

Pebble analyses in the various facies

Dissymetry-index. — This index serves mainly to distinguish pebbles modelled in periglacial and marine environments. As to the samples of the investigated area the variation is only small. Two average histograms of the conglomerates, and two of the terrace samples have been presented in fig. 28. Other samples do not materially differ from these.

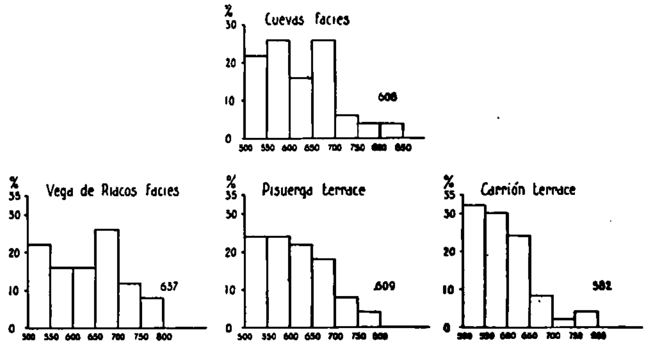

Fig. 28. Quartzite pebble dissymmetry of some average samples. (The numbers added are the median index values.)

From the histograms presented we may conclude that neither the limestone pebbles, nor the quartizite pebbles, show greatly dissymmetric forms. Their median values (the value at which 50 % of all ratios are greater, and 50 % smaller) only vary between 582 and 637. So the index of dissymmetry will not be mentioned any more when speaking about the morphometrical gravel analyses.

Roundness- and flatness-indices. — The roundness-index together with the flatness-index appear to be the most suitable values for reconstituting length of transport, palaeoclimate, and conditions of deposition. Tricart & Schaeffer (1950) determined the roundness of pebbles submitted to different agents. Although they only worked on a limited number of samples, distributed over several types of rocks, their results were of great help to us.

A favourable circumstance for our morphometrical analyses, was the homogeneous composition of the pebble deposits consisting chiefly either of limestones, or of quartzites. The homogeneity required for the determination of shape and of roundness was, therefore, easy to obtain. With the exception of the limestone conglomerate in the Cuevas facies, in all cases only quartzite pebbles have been used. It must be noted, however, that quartzites are not very suitable for morphometrical analyses. According to Tricart in some climates fluviatile, lacustrine, and marine shaping result in the same roundness. But in the investigated area we may exclude shaping in marine environments, and, at least for the pebble containing layers also lacustrine shaping, so that only fluviatile transport needs to be considered. The histograms permit the making of some conclusions on the climate during the shaping of the quartzite pebbles (Tricart, written communication).

For the morphometrical analyses only the indices of pebbles with a length between 2 and 10 cm were used. The sampling localities are shown in fig. 48.

Cuevas facies

As has been already stated, this facies includes the coarse detritic sediments alongside the borders of the basin.

Pebble composition. — The qualitative analyses show that the content of limestone pebbles of the conglomerates varies between 80 and 98 per cent. The other constituents are quartz pebbles of small size with lengths between 2 and 6 cm, a few quartzites, and more to the S some sandstone. The quartz derives mainly from the Wealden beds, which are exposed, together with the limestones, in the small strip of Mesozoic to the N of the conglomerates. Locally this quartz content increases to more than 60 %. In these cases the deposition may be compared with the so-called "grès de Las Bodas", described by Ciry (1939). These layers and their outcrops were already mentioned in chapter III.

Morphometrical analyses. — The morphometrical analyses appear to be important for determination of the depositional environments of the sediments in the Cuevas facies. The frequency histograms of the roundness-indices are presented in fig. 29, together with the histograms of the flatness-indices and with a number added for the median value. The adjoining table X mentions, besides the localities, the percentages of the various size classes of the pebbles.

TABLE X.

Additional data concerning the pebble analyses of the limestone conglomerates in the Cuevas facies.

sampling locality	length in cm				
	2—4	4—8	8—16	16—32	> 32
1a Arroyo Villarfria	9 %	39 %	40 %	10 %	2 %
1b Rio de las Cuevas, N part... (overturned conglomerates)	10	42	37	8	3
1c Perazancas	2	24	58	14	2
1d Rio de las Cuevas, S part... (horizontal conglomerates)	16	56	26	2	—

The roundness histograms show a clear double maximum, a higher in the class of badly worn pebbles, and a lower in the 300—400 thousandths class. A high top in the badly rounded class, together with a great number of broken pebbles, which in this case amounts to 20—30 %, may indicate deposition either in a periglacial climate, or in a fairly arid climate, or finally as mountain foot debris. The age which is Palaeogene, excludes a periglacial climate at that time, and also a fully arid climate may be excluded, the pebbles being hardly mechanically weathered, and the sand grains showing no indication of transport by wind (chapter VII). A deposition at the foot of mountains, especially in fans, is indeed obvious, the more so as the second maximum, and the rather high percentage of well-worn pebbles, indicate a deposit by rivers in a warm and fairly dry climate. The second maximum might be caused also by marine shaping, but this is excluded because of the low flatness values of the pebbles. The two frequency histograms of the flatness-indices are, indeed, also indicative of river transport (Cailleux 1956).

Origin and further history of the conglomerates. — The conclusions on the origin of the limestone conglomerates in the Cuevas facies, as inferred from the morphometrical pebble analyses, can be summarized as follows. In Palaeogene times great exposures of Mesozoic sediments, mainly limestones,

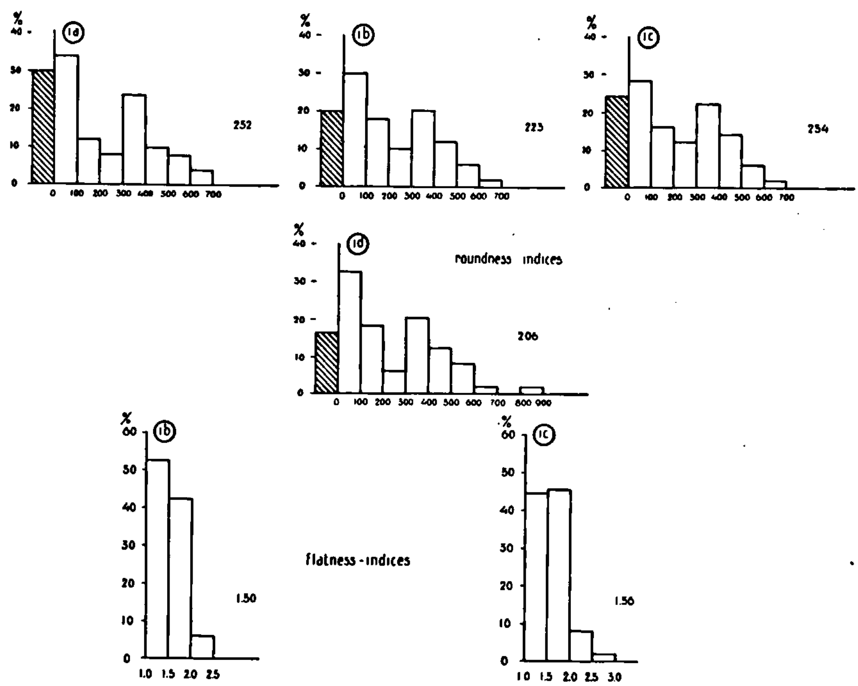

Fig. 29. Pebble roundness and flatness of the limestone conglomerates in Cuevas facies. (The numbers added are the median index values.)

existed to the N of the region. Climate and tectonic uplifts caused a strong erosion. The coarse detritus at the foot of the mountains was supplied by rivers of considerable capacity. Great fans, consisting of coarse limestone pebbles, were deposited, and between the fans finer sandy deposits with a rather high clay size content. A rising source area caused the fan deposits to obtain a great thickness.

The pebble roundness indicates a deposition in a warm and fairly dry climate, but a greater humidity must have prevailed in the mountains. The finer, sandy deposits have a reddish-brown colour, and their clay fraction has a fairly high percentage of kaolinite (chapter VIII, part 3), evidencing a humid climate, probably subtropical rather than tropical. The mountain area supplied some fine material from soils which covered the Palaeozoic rocks. Only limestone pebbles were supplied, and a very few quartzites, the latter being covered by other deposits, and partly by soils. Morphoscopical sand analyses (chapter VII) will give further indications on this problem.

Later the pebbly deposits were cemented by a calcareous cement to conglomerates, and the sandy deposits to sandstones.

During the Savian folding the conglomerates and sandstones have been overturned in the western part of the investigated area, together with the Mesozoic limestones. During and after this tectonic event the limestone conglomerates rather easily disintegrated, and the pebbles were redeposited. The layers found S of the overturned beds have only low dips, and have the character of a breccia. Still more to the south the strata become horizontal, and consist again of conglomerates, which now contain some sandstone pebbles derived from the sandstone intercalations in the original fans. Fig. 30 shows a section through the valley of the Rio de las Cuevas, in which good exposures of limestone conglomerates occur.

In the east, where the limestone conglomerates never occur in overturned positions, they only show a somewhat greater dip in the boundary zone (up to 50°). Here a distinction between pre-, syn-, and post-tectonic conglomerates cannot be made.

The various roundness histograms of the limestone pebbles always have the same shape. Their depositional environment, therefore, did not differ before and after the period of orogenesis. Either a more humid climate, or an increased vertical erosion, may have caused the amount of broken pebbles to be smaller in all post-tectonic conglomerates (histogram 1d), and these broken pebbles become already subangular (0—100 thousandts roundness class).

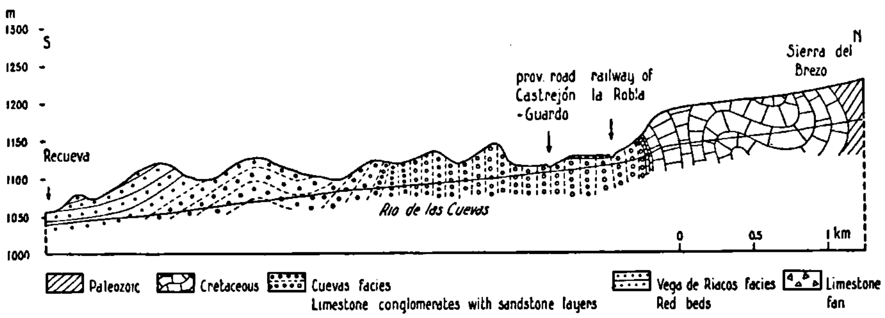

Fig. 30. Section through the Rio de las Cuevas.

Some indications on the decrease of the lengths of the limestone pebbles are given in table X. Generally an increasing roundness coincides with a decrease of the medium pebble size, down to the 2—4 mm class. But the limestone conglomerate belt is too narrow for making conclusions based on a change in pebble size. The most obvious change is that the boulders disappear, though cobbles smaller than 16 cm remain abundant.

Vega de Riacos facies

Pebble composition. — The pebbles deposited in the red beds are mainly quartzites. In small amounts also quartz, sandstone, and limestone pebbles can be found, and in a very small amount pebbles consisting of conglomerate.

The limestones originate partly from the limestone conglomerates and the Las Bodas layers in the Cuevas facies, partly they came directly from the Mesozoic mountain area. It is noteworthy that also a few Palaeozoic limestones pebbles, although not derived from the "caliza de montaña" (the so-called Brezo-limestone), have been found, which are altogether absent in the Cuevas facies. Sandstones are rare because of their rapid disintegration. They originate from the sandstone intercalations of the Cuevas facies, and from the red Triassic sandstones, which now occur only in the eastern regions of the mountains. The quartzites came largely from the Lower-Carboniferous Curavacas conglomerate exposed higher-up in the Cantabrian Mountains, but also from the

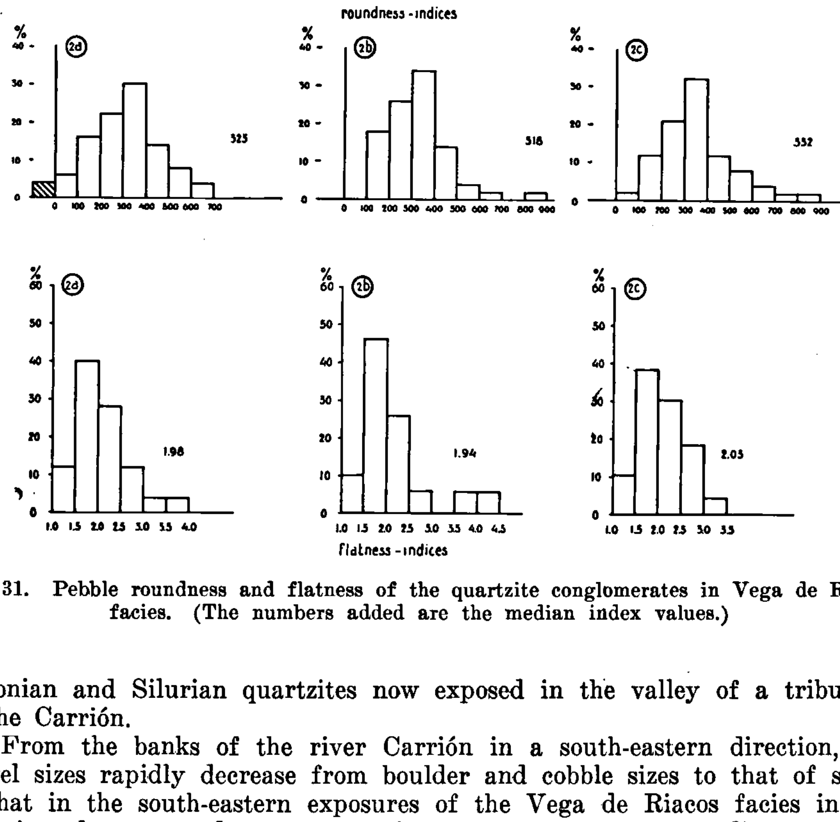

Fig. 31. Pebble roundness and flatness of the quartzite conglomerates in Vega de Riacos facies. (The numbers added are the median index values.)

Devonian and Silurian quartzites now exposed in the valley of a tributary of the Carrión.

From the banks of the river Carrión in a south-eastern direction, the gravel sizes rapidly decrease from boulder and cobble sizes to that of sand, so that in the south-eastern exposures of the Vega de Riacos facies in the investigated area sandstones form the greater part of the sediments. For this reason, pebble analyses could only be made in the western outcrops.

Morphometrical analyses. — Such morphometrical analyses can give, as we will see, some indications on the direction of supply and the environments of deposition. Fig. 31 shows the histograms of roundness-indices and flatness-indices of three samples; table XI gives supplementary data. The maximum roundness class is that of 300—400 thousandths. Broken pebbles occur only in a small percentage in the outcrop of Villalba de Guardo at the bank of the river Carrión. Also the percentage of slightly-worn pebbles is small. On the other hand the content of very well-worn pebbles with a great roundness-index is rather high. The composition as a whole, as shown by the histograms, might have been caused either by marine shaping, or by fluviatile shaping in a warm climate (Tricart).

Comparing the roundness histograms of this facies with that of the Carboniferous Curavacas conglomerate (fig. 32, after Nossin 1959), with its maximum also in the 300—400 thousandts class, and some 10 % of very well-worn components, there is a striking similarity. This may be due either to a common origin of both conglomerates, or to the Curavacas conglomerate having been the source of the Vega de Riacos pebbles. If the latter assumption is true, the transporting river will have only slightly increased the roundness, the Curavacas pebbles having been well-rounded before. The conclusion drawn from the shape and roundness of the quartzite pebbles applies in the first place to the depositional environment of the Curavacas conglomerate. This

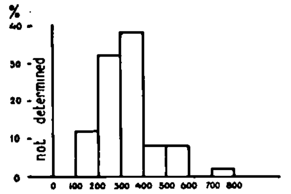

Fig. 32. Quartzite pebble roundness of the Carboniferous Curavacas conglomerate (after Nossin).

conglomerate has been proved to be a continental deposit (Kanis 1956). The climate at that time was warm and humid. The red beds of the Vega de Riacos facies, on the other hand, may also represent deposits of a warm and humid climate, data obtained from other analyses being in favour of this opinion. Then it is quite easily understood that the properties of the pebbles did not change in the Tertiary fluviatile environment. The quartzite pebbles directly derived from the Palaeozoic quartzites got in this warm and humid climate, a similar shape to that of those pebbles which came from the Curavacas conglomerate.

TABLE XI.

Additional data concerning the pebble analyses of the quartzite conglomerates in the Vega de Riacos facies.

sampling locality	length in cm				
	2—4	4—8	8—16	16—32	> 32
2a Villalba de Guardo	3 %	14 %	52 %	26 %	5 %
2b Vega de Riacos	2	62	34	2	—
2c Pisón de Ojeda	7	70	21	2	—

As has been said, the pebble sizes considerably decrease (table XI) towards the SE, which becomes clear when comparing the data on the outcrop of Villalba de Guardo (2a) with those of Vega de Riacos (2b). The pebble analysis of the NE corner (see histogram 2c) has the same character as that near Vega de Riacos (2b), though the 2—4 cm size class is small.

Origin of quartzite conglomerate. — In conclusion it can be said that the supply came from NW, and was transported towards SE. Possibly it came from the mountain range through a valley, lying at the same place as the present Rio Carrión valley, the upper course of which must have eroded both the Curavacas conglomerate, and Silurian and Devonian quartzitic rocks, as it does now.

The south-eastern exposures in the Vega de Riacos facies with their rather fine sediments would have been supplied from the coarse belt within this facies, and possibly from the Palaeozoic mountain range itself. A coarser detritus now outcropping near Alar del Rey can only have been supplied by a river, situated where at present the river Pisuerga is flowing.

The "raña" of Guardo and other remains of pediment debris

South of the small town of Guardo, along the river Carrión, the plateau consisting of Tertiary sediments is covered by a heterogeneous deposit of strongly mixed gravel and finer sediments. This cover has a thickness of several metres near the mountain range, showing a decrease towards the S. Very near the border of the Cordillera Cantabrica some limestone blocks still occur, but a little more to the S all boulders, cobbles and pebbles are quartzites. Most of the gravel is angular, though sometimes rounded pebbles are mixed in it. Although the name of the plateau, given by the inhabitants, is *páramo* because of its flat surface and its cover of heather, this name should be better avoided. Neither its genesis, nor its aspect can be compared with the true páramos in the S of the investigated area. The type of sediment deposited near Guardo is that of a *raña,* as described by various Spanish and non-Spanish authors. These rañas occur in some Spanish plateaus as coarse angular deposits on a flat pediment surface, extending from a bordering mountain range towards the interior of a basin. Locally they are also named *loma,* as e. g. in the region of Cistierna, prov. of León.

Morphologically rañas are nearly plains, often 5—15 km wide, having a slight slope towards the centre of the basin, and being a little steeper only near the mountain ranges. Data from the Tajo basin mention slopes varying between 0,7 and 2,5° (Ed. Hernández-Pacheco, 1928). The raña of Guardo not only slopes towards the S, but also towards the W and the E, so that it has the shape of a half-dome with very great curvature, which causes a sideward divergent drainage. In the W the river Cea takes up all arroyos, as does the river Valdavia in the E. The valleys of both these rivers caused an important erosion on the raña flanks, carrying away the finer sediments.

The raña deposits are separated by an unconformity from the underlying Tertiary deposits. Great outcrops show the cover of raña sediments gently dipping along with the surface, cutting off the horizontal beds of the Tertiaries. The cover varies in thickness between some metres and almost zero. During it deposition it was mixed with the underlying sediments grouped into the Vega de Riacos facies, the Carrión de los Condes facies, or the Relea facies. For this reason, a granulometrical analysis was not given. The shape and roundness of the sand grains derived partly from the subsoil was, however, modified by redeposition on the raña, as will appear from chapter VII.

The pebbles of the raña deposits are very angular. Their roundness histograms (numbered X) are presented in fig. 33. With the exception of histogram Xd, the number of broken and slightly rounded pebbles is high. It seems to be a sediment derived from mountain slopes in an arid climate, a pediment debris. As is shown in table XII the lengths decrease towards the S. This and the increasing roundness towards the S indicate a longer transport.

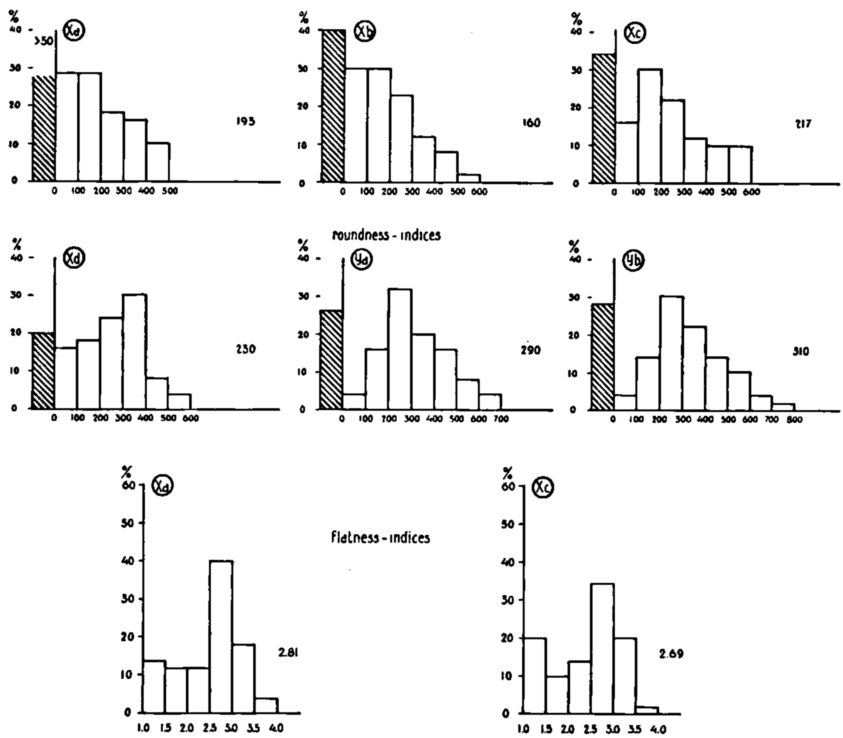

Fig. 33. Quartzite pebble roundness and flatness of the raña deposits. (The numbers added are the median index values.)

TABLE XII.

Additional data concerning the pebble analyses in the quartzites of the raña of Guardo (X), and the other pediment debris (Y).

sampling locality		length in cm			
		2—4	4—8	8—16	16—32
Xa	Mantinos	38 %	38 %	18 %	6 %
Xb	Fresno del Rio	32	52	16	—
Xc	Manguilla/Valderrábano	33	40	26	1
Xd	Relea	40	50	9	1
Ya	Torcevela/Oteros de Boedo	26	66	8	—
Yb	Trambos Uteros/Villameriel	30	58	12	—

The quartzites are strongly disintegrated, and have acquired red and yellow colours. Many pebbles can easily be pulverized in one's hand so as to become sand again. Obviously the cement of the quartzites has disappeared, possibly by dissolution. Similar features were described by Bakker (1957a, p. 18). The climatic implication will be considered in chapter X.

The genesis of the rañas has been for a long time a subject of much discussion. The data derived from the pebble analyses, especially the fragmentation and the angular to slightly-rounded shapes, as well as those from the sand analyses, in particular the high percentage of well-rounded, dull quartz grains, confirm the opinion as given already by Casiano de Prado (1864), who presumed the rañas to have been deposited in a warm climate with great variations in water supply spreading out the deposits on the pediment and on the flat surface of the basin at that time, that are sheetfloods.

Some other small remnants of pediment debris have been preserved, E of the raña. On the highest tops of the divides small occurrences of pebbles exist, of the same character as the raña deposits. The degree of roundness of the pebbles does not materially differ from that on the raña of Guardo. Only the pebbles are smaller. The histograms Ya and Yb of fig. 33 show the roundness histograms of a few localities where representative analyses could be made. Also the top of the Oteralbo hill, SW of Alar del Rey, bears a deposit of angular pebbles, which are finer and strongly consolidated so as to form a conglomerate. Here only a morphoscopical and morphometrical sand analysis was practicable.

All these isolated remnants are situated at a higher level than the highest terraces of the bordering rivers. They are sediments of the peripheral parts of the raña, at greater distance from the raña of Guardo, the gravel being fine. Possibly they have been transported farther into a south-easterly direction by rivers flowing over the high surface towards the basin centre. Even in the S of the investigated area, on top of the Páramos-limestones, occasionally quartzite pebbles, sometimes even fairly large ones, have been found. Their quantity and size exclude their being brought there by man. Neither are they remainders of Quaternary terraces, the level being too high (130—140 m) above the river bed. So the rivers of the raña time, or of a somewhat later time, though earlier than the oldest terraces, must have deposited them.

River terrace deposits

The wide valleys of the whole investigated area contain Quaternary pebble deposits on terraces at various heights along the slopes, and on the valley bottoms. These ediments can areally be divided into three groups, namely those along the river Pisuerga, those along the river Carrión, and those occupying the region drained by the rivers Boedo and Valdavia. The pebbles in the valleys of the rivers Burejo and Ucieza, with the exception of the southern part of the latter, are of minor importance. The palaeogeography of the Pisuerga river on the one hand, and the Boedo and Valdavia rivers on the other hand, are closely related, but the terraces have to be considered separately.

Terrace sediments of the Boedo and the Valdavia. — In the mountain region along the upper course of the present river Pisuerga a terrace is known at a level of 100—120 m above the river (Nossin), which terrace has a great extension near Cervera de Pisuerga. But south of this small town the present Pisuerga bends towards the E to flow in the direction of Aguilar de Campóo, where it again resumes a southern direction before entering, near Alar del Rey, the area investigated by us.

The terrace deposits, however, can be followed from Cervera into a southern direction passing through the southern Mesozoic belt of the Cantabrian Mountains at the Brezo gate (Nossin). South of this, near Dehesa de Montejo, where it enters into the Castilian high plains, the terrace becomes very wide, and here the present river Boedo curves into this train of pebbles, and cuts a wide and some 40 m shallow valley into it. Southward the pebble deposit continues as a wide terrace along the Boedo, though the pebbles alsc cover the valley slopes and bottom. Downstream of the locality where the Boedo valley approaches that of the Valdavia, until their confluence with the Pisuerga, and also in a valley now occupied by an unimportant river Vallarna, S of Osorno, all valley slopes not exceeding 30° possess a cover of gravel. The composition of this gravel, with 98—100 % of quartzites, always remains the same. Even the ratios between the differently coloured quartzite pebbles show no variations. The cover is rather thin, and becomes even thinner towards the S.

Into these gravel deposits various terraces have been cut by the Valdavia and Boedo; they are rather narrow, if compared with those of the Pisuerga. Two levels can clearly be distinguished, a lower at 5—15 m, and an upper at 25—35 m above the present valley bottoms. Higher-up only small remainders of possibly former terraces exist, among which are the continuations of the Cervera- and Dehesa-terraces.

As has been stated, the river Valdavia borders the raña of Guardo, which lies at a level of 120—130 m above the recent rivers. The terrace deposits of the higher Dehesa-terrace, to be called the *T1*-terrace, coming from the NW, seem to butt against the raña, N of Bascones de Ojeda and La Puebla de Valdavia. Because the Valdavia valley is found at this place, it is difficult to see that the *T1*-terrace really remains some 20 metres below the raña level. But other rivers, as e. g. the Carrión and the Esla, which are flowing through a raña, clearly show their *T1*-terrace level to be situated some 20 m below this raña level. The terrace sediments must indeed be more recent than the pediment debris.

The pebble deposits of the *T1*-terrace near the Brezo gate have been analyzed by Nossin, their continuation through the high plains has been sampled by ourselves. The frequency histograms of the roundness-indices are shown in fig. 34. The terrace of Cervera, still in the mountain region, shows a great conformity with the histogram of the Carboniferous Curavacas conglomerate (fig. 32), having a maximum in the 300—400 thousandths roundness class, but the percentage of broken pebbles is very high, sometimes even over 50 %. The terrace near Dehesa, however, has its maximum in the roundness class of 100—200 thousandths, the broken pebble content remaining high. This general decrease of the roundness-indices here, can only be explained by mixing with other, less rounded pebbles, which were already present at this place. We presume that also along this river, which flowed through the wide Brezo gate, a raña has existed. The cover of quartzite pebbles must have been rather thin, the Dehesa terrace deposit being not thicker than the Cervera terrace deposit. This must be due only to limited supply of quartzite pebbles, which were not exposed on a great surface in the source area. So the raña may not have reached as far in the high plains as did the raña of Guardo.

In the area investigated by ourselves, the count ABc shows the same shape of histogram as the Dehesa terrace (ABb). The broken pebble content has considerably decreased, and the roundness indices generally have increased, due to a longer transport.

A little more to the S the impact against the raña of Guardo resulted in a change of the roundness-indices. Here a mixing with the more angular pediment pebbles took place again, and possibly also with pebbles eroded from the underlying red beds in the Vega de Riacos facies. Counts Bd in the valley of the Rio Boedo, and Be and Bf in that of the Valdavia, clearly show this mixing. But downstream the roundness values again increase. In histogram Bf the maximum is already displaced to the 200—300 class, but it is only at the confluence of Boedo and Valdavia, N of Osorno, that a final rounding is reached, where a great number of pebbles have already passed the 100—200 roundness class, as is shown in histogram Bg.

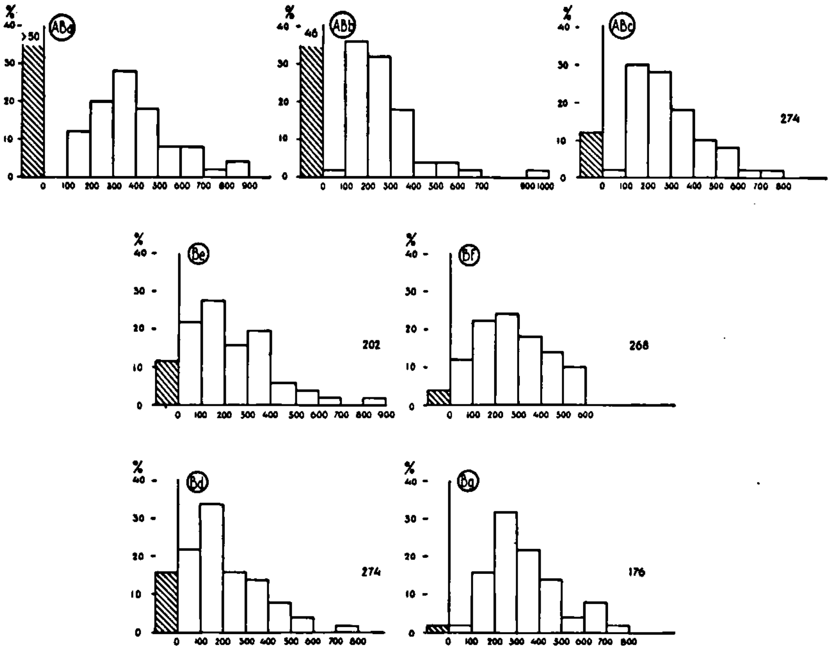

Fig. 34. Quartzite pebble roundness of the rivers Boedo and Valdavia terraces. (The numbers added are the median roundness-index values; the counts ABa and ABb are after Nossin.)

From whatever level the samples are taken, all have the same type of histogram. This fact, together with the thinness of the cover, lead to the conclusion that the lower terrace levels of Boedo and Valdavia are covered with redeposited pebbles. After the deviation of the Pisuerga, to be mentioned below, the remaining rivers were of little importance, and had no great pebble supply of their own. During the climatic changes in Quaternary times, only small terraces could have developed, though the underlying sediments are relatively weak.

Pisuerga terraces. — The Pisuerga enters into the investigated area near Alar del Rey through a gorge cut into the strongly consolidated Tertiary conglomerates. But these conglomerates having once been passed, the valley enters into a region of softer sandstones and sands, so that it widens, exhibiting various terrace levels. Only three levels can be distinguished, namely a higher level at 70—80 m above the present river (*T2*-terrace), and two lower levels at 20—30 m (the *T4*-terrace) and 5—15 m (the *T5*-terrace), respectively. The 100—120 m terrace (*T1*-terrace) found high upstream, deviated through the Brezo gate and disappeared into the valleys of the Boedo and Valdavia rivers. Until the region near Valladolid, where some remains are found (F. Hernández-Pacheco 1929), neither this highest terrace, nor isolated pebbles at this level, are found any more along the river.

The *T2*-terrace, occurring along the present Pisuerga course, is found in various localities. The histograms of its deposits are presented in fig. 35a, together with those of the lower terrace levels. East of the Pisuerga we limited our investigations to a short distance from the river, so we have considered

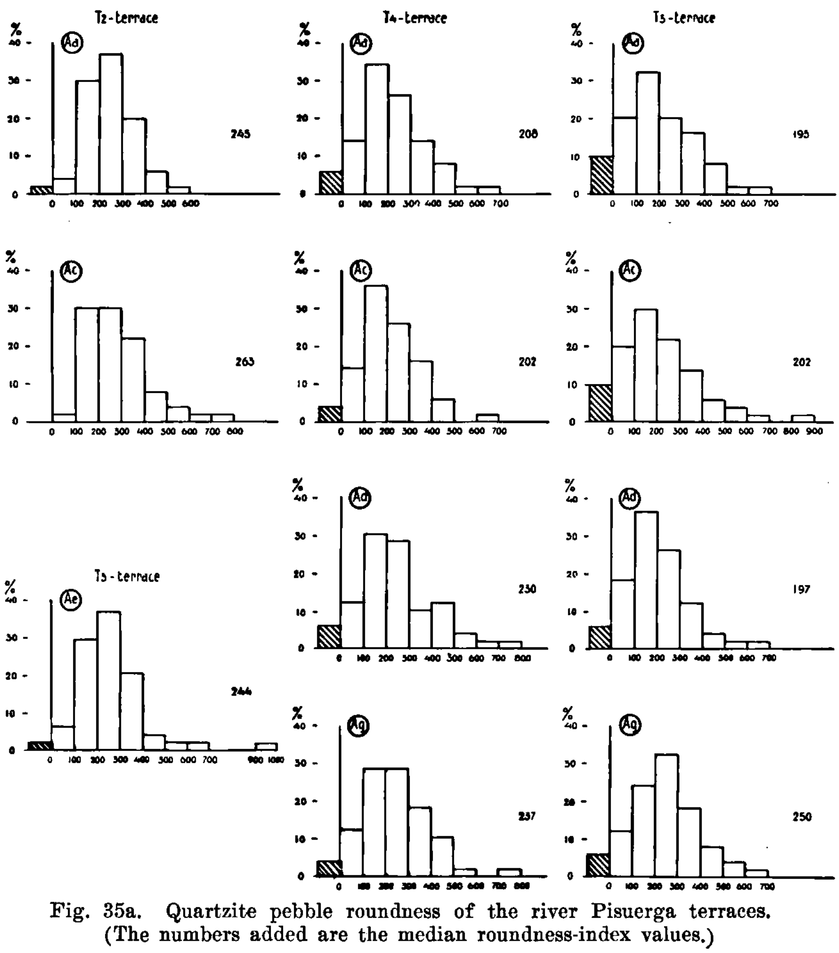

Fig. 35a. Quartzite pebble roundness of the river Pisuerga terraces. (The numbers added are the median roundness-index values.)

the *T2*-terrace only when it is found within this zone. A more detailed study on all terraces of the rivers Pisuerga and Carrión will be published later. With the exception of a locality near Herrera de Pisuerga (histogram Aa), all investigated terrace remainders lie on the western bank of the river. The *T2*-terrace part of Herrera, at the Pisuerga's eastern bank, near the NE of the investigated area, lies opposite to a steep western slope without terraces. More to the S some remainders can be found between Ventosa de Riopisuerga and Osornillo, but on entering the campiña region they disappear. Where the páramo region begins, only one *T2*-terrace deposit has been found. It lies on and against gypseous marls, and therefore it is strongly cemented, thus having become a conglomerate. This is a general phenomenon with terrace deposits in this region; consequently it is difficult to obtain a representative set of pebbles for making a count.

The histograms of the *T2*-terraces show the same shape as those of the *T1*-terraces. They have not been greatly influenced by periglacial climates during glaciations in the mountains (Tricart, written communication).

More influence of a cold climate is shown by the lower terraces, i. e. the *T4*- and *T5*-terraces. They have a greater percentage of broken pebbles, and their maximum roundness lies in the 0—100 class. They may represent a reworked periglacial gravel deposit. The pebbles become slightly rounder towards the S.

Between Melgar de Yuso and Cordovilla la Real the present Pisuerga again passes through a gorge, but here it is a narrow passage through the páramo region, where only a small *T5*-terrace exists, besides the valley bottom. Near Cordovilla la Real is the confluence with the river Arlanzón, which, coming from the region around the town of Burgos, flows through a wide valley towards the SW. From here the Pisuerga curves in the same direction. Alongside its course a conspicuous *T5*-terrace level exists, and also rather extended remainders of the *T4*-terrace, the deposits of both of which have mostly been consolidated to conglomerates. From Dueñas, a little S of Venta de Baños, on to Valladolid the Pisuerga terraces have been studied by F. Hernández-Pacheco (1929).

East of Astudillo, where a wide valley, now occupied by a very small arroyo, comes into the Pisuerga, some small, strongly consolidated terrace remnants are found. They form a level at 50—55 m above the present river (*T3*-terrace). Their pebbles are only quartzitic. The roundness histogram (Ac) is of the same type as those of the *T2*-terrace. On the origin of this *T3*-terrace, not found anywhere else in the whole of the investigated area, nothing can be said. Further detailed terrace studies may give more indications.

The lithological composition of the various terraces also is monotonous, as they mainly consist of quartzites. To the N near Herrera small limestone pebbles occur, but towards the S they rapidly disappear. A few conglomeratic pebbles, originating from the Trias conglomerate lying N of the investigated area, and supplied by the tributaries Camesa and Rubagón (Nossin), can be found along the whole course of the present Pisuerga. These pebbles occur in all three terrace levels (*T2, T4* and *T5*). Triassic sandstone pebbles, of a red and sometimes white colour, also are present in the N of the investigated area, but they rapidly disintegrate, as do the Wealden conglomerates. After that, only small quartz pebbles, of less than 4 cm, remain in the gravel size fractions of all pebble deposits, in percentages varying between 2 and 4 %.

The roundness histograms of the pebbles in the present river bed (fig. 35b) show a mixing of pebbles supplied from the valley slopes, and by the present river itself. The roundness slowly increases into a southern direction towards the 200—300 thousandths class. After having attained this value, the passing through the páramo gorge causes a slight decrease in roundness. After the confluence with the river Arlanzón the roundness increases again.

The origin of the terraces of most rivers in Spain is generally attributed to the alternation of cold and temperate climates in Pleistocene times (Ed. Hernández-Pacheco 1928). The only traces of real glacial phenomena observed up till now in the Spanish mountains date from the last, and possibly the penultimate glacial. The histograms of the Pisuerga pebbles show indeed a difference between the higher levels (*T1*, *T2* and *T3*) and the lower levels

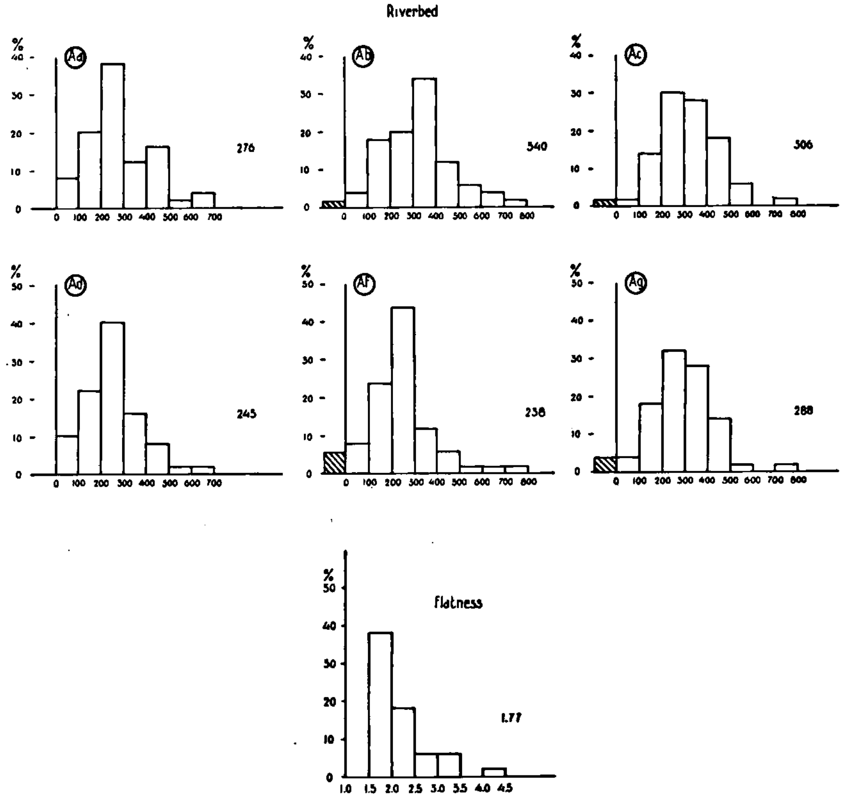

Fig. 35b. Quartzite pebble roundness and flatness of the present Pisuerga riverbed. (The numbers added are the median index values.)

(*T4* and *T5*). The pebbles of the higher terraces demonstrate a purely fluviatile shaping, those of the lower terraces show evidence of periglacial supply as appears from the percentage of broken and badly rounded pebbles. This is in agreement with the opinion that only during the last two cold phases real glaciations occurred in the Cantabrian Mountains. It also implies that the *T4*- and *T5*-terraces both lower than about 30 m should date from the last two glacials, respectively the higher terraces having been formed in older parts of the Quaternary.

Carrión terraces. — The river Carrión, bordering the investigated area in the W, first passes through the axis of the raña of Guardo after leaving the Cantabrian Mountains. Along its whole course from Guardo to Carrión de los Condes it has not tributaries. The bottom of the present valley lies about ± 120 m below the raña level, and is mostly bordered by steep valley slopes.

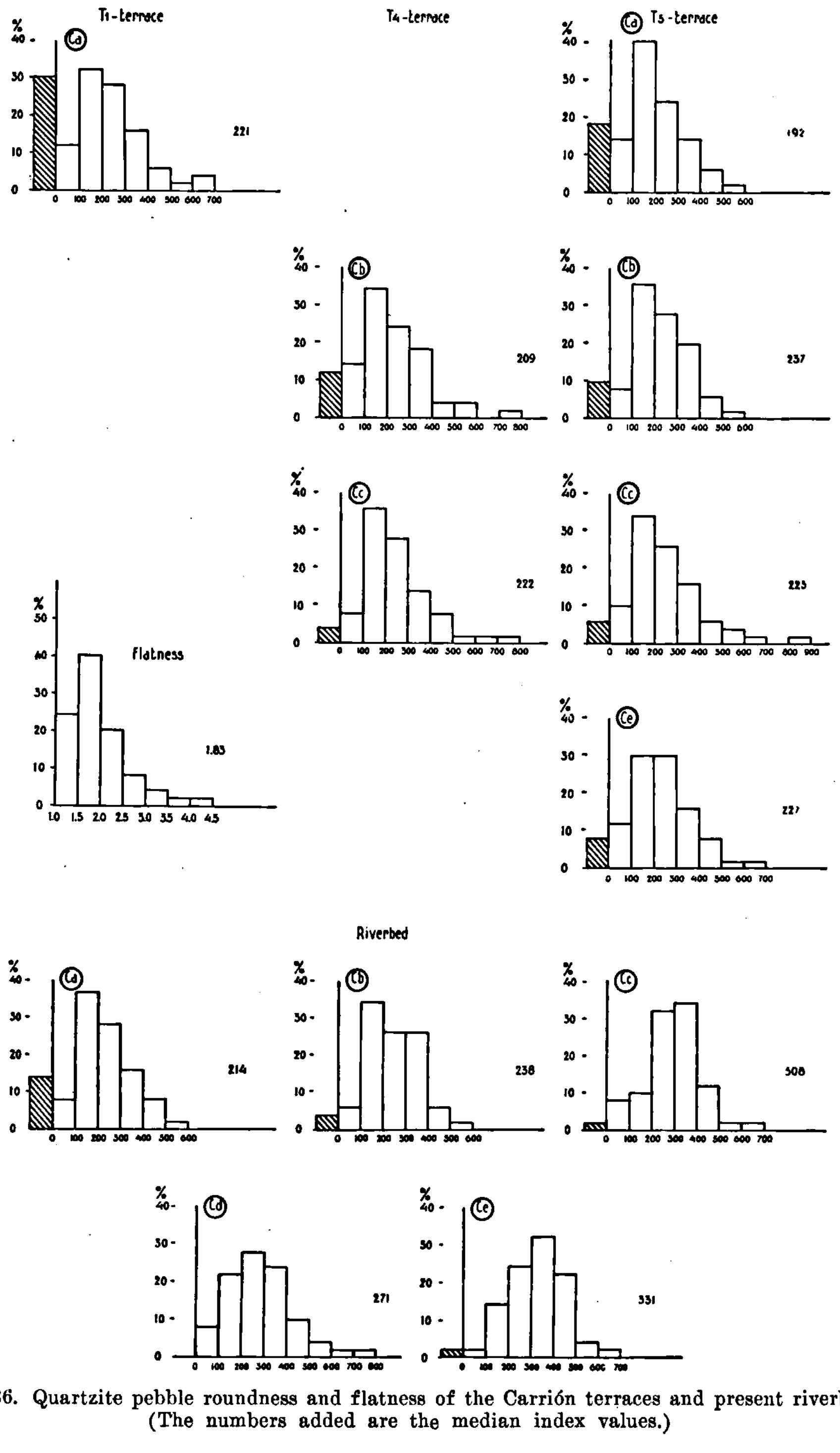

Fig. 36. Quartzite pebble roundness and flatness of the Carrión terraces and present riverbed. (The numbers added are the median index values.)

The only terraces preserved are the *T1*-terraces at 100 m above the river, and the *T5*-terraces at 5—15 m. South of Saldaña, where the campiña begins, also some remnants of a *T4*-terrace can be observed. The Carrión being the western limit of the investigated area, the terraces at the western bank of the river have not been investigated.

As is well-known, valley slopes do supply great amounts of pebbles to river valleys (see e. g. Tricart 1958). So it is not surprising that the raña of Guardo supplied a lot of pebbles to the Carrión terraces. Indeed, the histograms of the roundness-indices, as shown in fig. 36, have their maxima in the lower roundness classes, and have great percentages of broken pebbles. Southward the roundness becomes greater, the broken pebble content rapidly decreasing, and the well-worn classes increasing. Naturally also the lengths decrease towards the S.

When passing throug the campiña, the *T5*-terrace is wide, and there is even a small remainder of a *T4*-terrace near the village of Lomas. Other levels do not occur, because the Carrión, during the times of sedimentation of the *T1, T2* and *T3*-terraces, did not flow along its present course, as will be explained in chapter IX.

The roundness histograms of the Carrión pebbles, both of the terraces, and of the present riverbed, are of the same character as those of the Pisuerga. Only the supply from the raña slopes altered the histograms in the northern part.

The lithological composition is even more monotonous than in the Pisuerga. Nearly all pebbles are quartzites, with only a few quartzes. The northern section has still some limestone pebbles, which must originate from the Mesozoic strata and the Tertiary limestone conglomerates. Palaeozoic limestones are absent, as in the present riverbed. Even at those places within the mountain area, where the Carrión flows through the Brezo-limestone, no pebbles are at present supplied to the riverbed, probably because of rapid solution of this limestone.

Final remarks

The pebble analyses of both Tertiary and Quaternary sediments have provided satisfactory results. Especially the roundness-indices, determined by the method of Cailleux, allowed some conclusions to be drawn on sedimentation environments, and even sometimes on palaeoclimate. Together with grain size, and sand and clay analyses they are of great help to sedimentological studies, also of older sediments.

CHAPTER VII

SHAPE AND ROUNDNESS OF SAND GRAINS

Introduction

For the interpretation of the possible origin of a sediment, the study of the quartz grains in sand can be of great importance. Cailleux developed a quite simple method. After his paper (1937) on some periglacial phenomena in Europe, in which he already distinguished three types of shape of quartz sand grains, namely: (1) not worn, (2) (slightly)-rounded — glossy, and (3) well-rounded — dull, the method has been supplemented (1952a) also by a roundness-index. This index is expressed by $\frac{2000\ r_s}{L_s}$, with r_s and L_s corresponding with r and L of pebbles. When studying sand grains by means of a binocular microscope, only the apparent values can be measured. The objections made against the roundness index of pebbles also apply to that of sand grains. But the determination of the parameter l_s would be difficult because of the irregular shape of most quartz grains, and so would take too much time.

It was again Kuenen (1958), who made experiments on this problem. His conclusion is that mechanical abrasion of quartz grains of a diameter of less than 2 mm by flowing water is extremely slow, and quite imperceptible for grains below 0,5 mm. The course of any river, however long, is still so short that in fact mechanical rounding is negligible. The curves of the median values of the roundness-index of fluviatile sands, plotted against the length of the grains, as did Cailleux, indeed approach 0 below the 0,5 mm line. Somewhat larger sand grains become at best slightly rounded. So well-rounded quartz grains must have been modelled either by wind, or by chemical attack. The so-called water-worn grains (Cailleux) may possibly have passed several erosion and sedimentation cycles, or have been attacked partly by others agents, and later slightly modelled by water.

Recent studies by Bakker (1955, 1957a) and Bakker & Müller (1957) showed that in tropical humid climates quartz sand grains do not round at all. The grains are so strongly disintegrated that they break to pieces during mechanical erosion. Rounding is, therefore, a process of more temperate climates. The presence of a great percentage of non-rounded grains in a sand fraction may thus often be due to specific climatic conditions, and not to a short transport only. This fact is often neglected by various investigators.

The sands from our samples have been prepared in a different way from that proposed by Cailleux (see chapter VIII). The fraction 0.5—1.0 mm has been used for roundness and shape analyses. 100 grains of each sample have been taken to estimate their L_s and r_s.

The drawing of curves of median index values plotted against the length of the grains, as did Cailleux, is rather unsuitable for this type of investigation.

When, for instance, the class with a length of 0.7 mm is represented only by one or two grains, both with a roundness-index greater than 500, a top will be formed, only depending on a minute number of grains. It is better to give one median index value for only the more or less rounded grains, together with the precentage of slightly-rounded — glossy, and of well-rounded — dull grains.

Distribution of sand grain types

Fig. 37 shows the distribution of the types of the sand grains over the various Tertiary facies. The greater part, always over 50 %, in the whole investigated area consists of angular grains, that is of grains with an I_s (roundness-index) $= 0$. This may be a consequence of either transport over a short distance, or fragmentation in a warm and humid climate.

Fig. 38 shows the average roundness distribution of the Quaternary sediments. Four different types can be distinguished: (1) the X- and Y-series of the raña and pediment deposits, (2) the A-series of the Pisuerga terrace deposits, (3) the B-series of the Boedo/Valdavia terraces, and (4) the C-series of the Carrión terrace deposits. The values in the various levels do not show apparent differences.

The content of dull grains may be caused either by wind action in a dry climate, or by chemical attack. Pettijohn (1957, p. 70), when mentioning the formation of pitted grains by encroaching carbonate cement, states that "Incipient action of this type might produce a frosted grain". Such chemical attack may be presumed for some sediments in the investigated area.

Cuevas facies (1). — The sediments in this facies are not very sandy. Representative amounts of sand grains could only be obtained from the sandstones intercalated between the conglomerates. The sandy fractions chiefly derive from the soils which covered the rocks of the mountain area. As the Cretaceous limestones did not provide much quartz sand grains, these grains must originate from the Palaeozoic quartzitic rocks and conglomerates. The very high percentage of quite angular sand grains then may be due to early fragmentation (Bakker 1957a, Bakker & Müller 1957), and a fairly short transport afterwards.

The absence of dull grains indicates that no strong wind action occurred during the sedimentation of the conglomerates and sandstones. Chemical attack is not likely, the grains being not even pitted or rounded.

Vega de Riacos facies (2). — The sand size fraction of most deposits in the Vega de Riacos facies is less angular. Both types of rounded grains increase in number, compared with the Cuevas facies. This presence of rounded, glossy grains must be due to supply from the source area, because the length of transport was too short to cause wear, even to a small amount. The non-rounded grains have been formed by fragmentation, considering the warm and humid climate, in which the red beds were deposited.

Chemical attack is the most probable reason for the presence, although in percentages never exceeding 8 %, of well-rounded, dull grains, because all sediments in the Vega de Riacos facies have a considerable lime content. Also the grains with a low roundness-index value, and those with $I_s = 0$, already show pitting, which is an argument in favour of Pettijohn's assumption. This attack must have occurred later, when the climate was no more warm and humid.

Carrión de los Condes facies (3). — The sediments presenting this facies

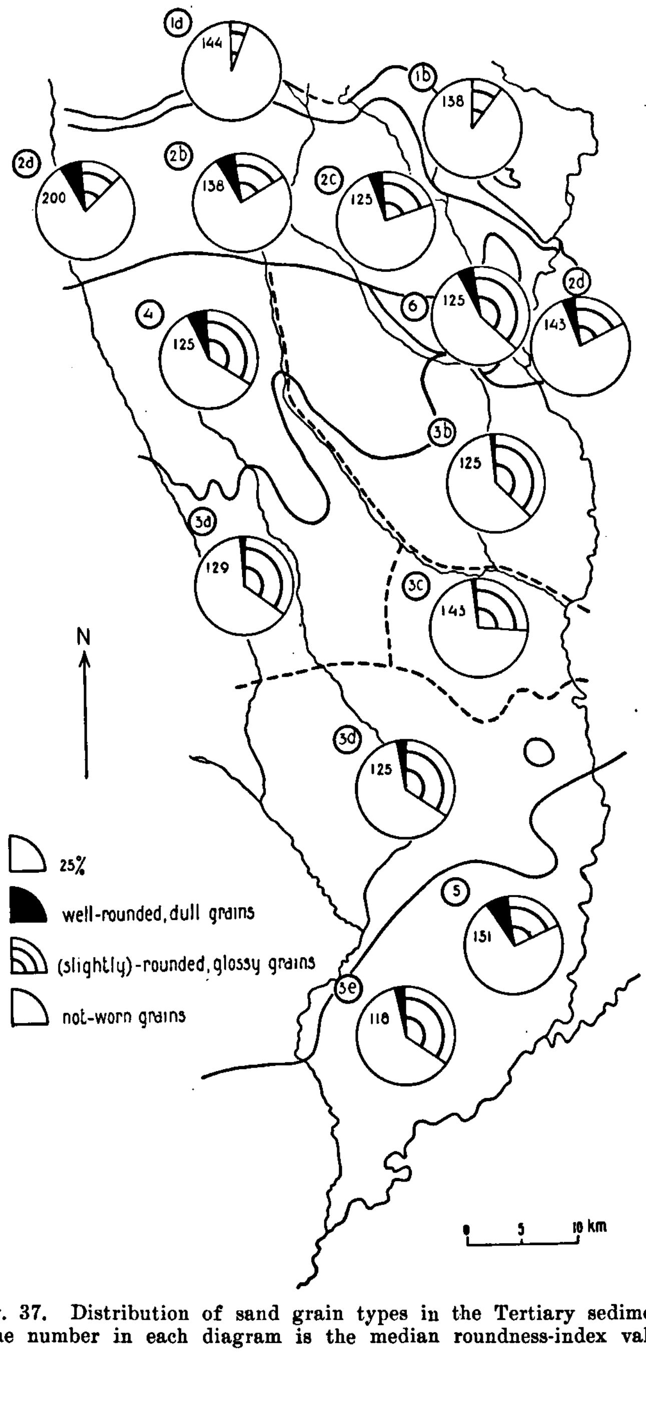

Fig. 37. Distribution of sand grain types in the Tertiary sediments. (The number in each diagram is the median roundness-index value.)

clearly have been deposited for the greater part by rivers, and partly in lagunas. The water supply in Vindobonian times must have been considerable. The percentage of dull sand grains is very small, varying between 1 and 3 %. The lime content of the sediments is fairly low, so chemical attack of sand grains was less, and pitting of grains was only inconsiderable. The content of glossy grains, on the other hand, is higher, namely 27—38 %, but the median index values remain low (118—143), which means that most quartz sand grains are only very slightly rounded. This could have happened by bumping and rolling in rivers, where sharp edges of the grains were slightly blunted, so that the roundness-index becomes determinable.

Relea and Zorita facies (4 and 6). — Lying on top of the yellow sediments in Carrión facies, and partly on the red beds in Vega de Riacos facies, nearer to the border of the mountain area, these deposits of Pontian age must have been mixed or reworked with the underlying sediments. As the supply came from the NW, the supply areas were the Palaeozoic rocks in the mountains, the limestones of the Mesozoic (to a very small degree), the sediments of the early Tertiaries, and finally the red beds. Having a higher lime content, the sediments contain a higher percentage of dull and well-rounded grains, compared with the sediments having the Carrión de los Condes facies. This percentage is almost equal to that of the red beds, also where the deposits of the Relea facies overlie those in Carrión facies. Many non-rounded grains are pitted. The percentage of 35—40 of glossy grains, and the median index values of 125, which apparently are low, can be explained by slight fluviatile action.

Páramos facies (5). — The very fine calcareous sediments caused great difficulties in preparing samples for sand analysis. Only the samples from which a heavy mineral slide could be obtained, also provided a certain amount of sand grains. But many samples contained less than 100 grains, the minimum number for a representative count. The conclusions drawn from these analyses have to be considered with due reserve.

The average percentage of dull grains is 8, that of glossy grains 20. The angular grains show extreme pitting, for which the high lime content must be responsible. The presence of glossy grains, the number of which is smaller than in the river deposits in the Carrión and the Relea/Zorita facies, may be due to a limited supply from rivers.

Raña and pediment sediments (X and Y). — As has been said, the finer fractions of the deposits show mixing with the underlying sediments. Nevertheless the sand grains have a different shape and roundness. So this must be due to changes during redeposition, particularly as a consequence of the climate. As can be concluded from the high percentages of well-rounded, dull grains, as well as from the pebble analyses, an arid climate with strong wind action must have prevailed at that time.

Pisuerga and Boedo terrace deposits (A and B). — Considering their origin, as well as considering the distribution of the various classes of sand grains, the terraces can be treated together. Dull grains are only rare, and occur near the mountain border, the amount decreasing towards the S. Only in the páramo region the number slightly increases again. When passing through the Tertiary deposits, mainly in the Carrión de los Condes facies, the rivers locally took up angular and slightly-rounded, more or less glossy, grains. The climatic conditions during the deposition of the various terrace levels did not substantially alter the shapes of the sand grains, the content of dull grains

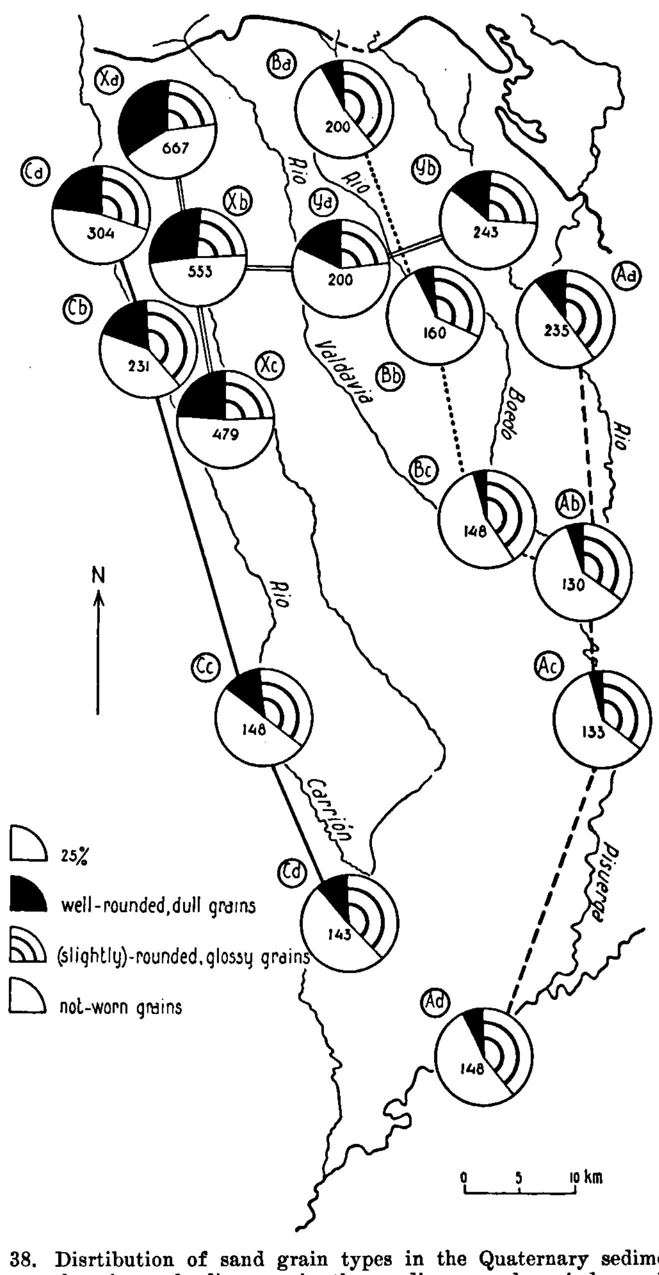

Fig. 38. Disrtibution of sand grain types in the Quaternary sediments. (The number in each diagram is the median roundness-index value.)

remaining low. In the Cantabrian Mountains Nossin found similar compositions of the terrace sediments.

Carrión terrace deposits (C). — The Carrión must have been strongly supplied with sands by the raña deposits, as it was with pebbles. The percentage of well-rounded, dull grains is, therefore, high in the northern part of its course through the investigated area. This great percentage in the N causes a rather high median index value. A later change did not occur for the same reasons as with the Pisuerga. So this percentage decreases towards the S, where the median values become lower (Cc and Cd). Glossy grains occur in the same amount as in the other rivers.

Conclusions

In conclusion it can be said that the study of shape and roundness of sand grains cannot provide definite indications on depositional environment, and on palaeoclimates in particular. Until now very few experimental studies, which go into much detail, on rounding and polishing of quartz grains have been made, and the results are not definite yet. So the conclusions on what we observed cannot be but provisional. Strong wind action could form dull grains. A high lime content in sediments caused a chemical attack which at first resulted in dull grains, and by continued action, in pitted grains. As detailed studies on the sand size fraction in the source areas of both Tertiary and Quaternary deposits are still to be made, a comparison with the supply area is very difficult. The results of the sand analyses mainly serve as further confirmation of data obtained by other analyses, as e. g. grain size, composition and shape of pebbles, and heavy and light minerals.

Appendix

After termination of our morphoscopical and morphometrical sand grain study, a paper has been published (1958) by the "Laboratoire de l'Institut de Géographie de l'Université de Strasbourg", under the direction of Tricart, on an improved method for quartz sand analysis. The most important result concerning the morphoscopy of the sand grains is the distinction of a fourth type, the pitted grains. The distinction of glossy and dull grains, as introduced by Cailleux, is maintained; the non-worn grain class has to be limited to grains having preserved their natural lustre. Pitted surfaces mostly occur on rather angular grains, and must have been developed in a tropical climate.

The sand grains of many samples from the investigated area, especially those from the Vega de Riacos facies, often show this type of pitted, angular grains, as was already mentioned. Since they develop only in warm and humid climates, the high content in the red beds thus may indicate a tropical climate during the sedimentation of these deposits. This conclusion agrees with the results obtained by the grain size analysis.

In the paper cited above five roundness classes were also introduced, in order to facilitate the morphometrical sand analysis. Our analyses having been finished by then, we have not been able to use this method in this work.

CHAPTER VIII

MINERAL ASSOCIATIONS

1. HEAVY MINERALS

Preparation of samples for mineral analysis

Unconsolidated materials were first freed from their organic components by treating them with H_2O_2 6 %. All coherent material could be disintegregated by HCl. For the removal of the high carbonate content, of the iron oxide coatings of the mineral grains, and of possible sulfides, the samples have been boiled with HCl 36 %, being rubbed meanwhile to help the process of breakage, and then treated with HNO_3 70 %. After boiling with HCl, and again after boiling with HNO_3, the sample had to be made acid-free, and the repeated decantation was at the same time employed for the removal of all particles smaller than 50 microns.

In addition, the method, as described by Leith (1950), for the removal of iron oxide coatings without risk of a possible loss of any less resistant minerals through boiling has also been tried. The material containing carbonate and iron was treated with H_3PO_4 85 %. Our experience was that by this method not all coatings disappeared. In consequence, some coated light minerals retained a specific gravity greater than that of the heavy liquid, and so came into the heavy fraction.

When the sample had been made free of acids, clay and silt, it was dried, cooled and sieved through a 1000 micron and a 500 micron mesh screen. The size class 1000—500 micron was used for the morphoscopical and morphometrical sand analysis. The fraction smaller than 500 micron was then used for separation with bromoform (s. w. = 2.89) in a special funnel. From the heavy separates slides were made with Canada-balsam.

Mineral counts and description of the grain types

From the heavy mineral content of the single slides, countings have been made as described by Edelman & Doeglas (1933). The contents of opaque minerals are given as percentages of the total. The contents of the various translucent grains are given as proportional percentages of the total amount of those translucent grains.

Opaque minerals. — This group unites all grains, which are not transparent nor translucent. Generally they are presumed to be ores which did not disappear during the preliminary preparation of the sample.

Tourmaline. — Often well-rounded grains, sometimes prismatic. Their colour is commonly dark, brown, yellow-brown, green, or more rarely, blue or pink. Strong pleochroism occurs, but grains without it are not rare.

Zircon. — All the three types known, namely prisms with pyramid terminations, "well-worn" eggs and broken grains, are frequent. Usually colourless. Pink to red grains are also common.

Garnet. — In the counting tables, subdivided according to the Dutch system into two groups, one containing the colourless to pink grains, the other the red, yellow and brown grains. Nearly all grains are clear. Their forms are angular, often with mosaic facets. Inclusions have only been found in the dark-coloured grains.

Rutile. — Commonly elongated grains with rounded pyramidal ends. Their colours vary from yellow to reddish-brown, no colour being dominant.

Anatase. — Rare, mostly nearly opaque grains.

Brookite. — Occurring more frequently than anatase. Corroded grains of yellow colour, showing typical strong dispersion.

Staurolite. — Often rounded grains with irregular ends. Their colour is yellow, rarely brown, always with marked pleochroism. Most slides contain grains with a few inclusions. But some slides, which have a high number of staurolites, contain some grains with so many inclusions that the individual grain becomes almost opaque. They can then be identified only by their bright interference colours.

Kyanite. — Rather common, sometimes abundant. The grains are elongate and colourless. Blue pleochroism has not been found. Inclusions are few only.

Andalusite. — This mineral occurs as great worn, broken, irregular crystals, mostly with strong pleochroism and many inclusions. The variety *chiastolite* was sometimes found.

Sillimanite. — Rather rare as grains and very rare as fibrolites.

Epidote. — Not frequent. Small, partly converted, troubled grains. Colourless to pale greenish. Sometimes recognizable by the "compass-needle" interference figure.

Topaz. — Not frequent, but regularly seen. Colourless grains with a low relief and bright interference colours.

Alterite. — This name, introduced by Van Andel (1950), unites all grains, which are not opaque, and cannot be brought into one of the other heavy minerals.

In small quantities, or as individual grains, have been observed: *hornblende, augite, hypersthene, corundum, olivine* and some others. These minerals are not important for the characterization of the association.

Since the minerals staurolite, kyanite, andalusite and sillimanite mostly appear together, they have, when necessary, been united into one group, that of the metamorphic minerals. The more resistant minerals, which are therefore more abundant in older sediments, are tourmaline, zircon and rutile, taken together into a group of "resistant minerals". Garnet, alterite and the more rarely found minerals have been grouped together as "other minerals".

A first glance at the tables shows that the mineral associations are very monotonous. Tourmaline — zircon — rutile form the greater part of the translucent grains. Only the variations in their percentages are important.

Epidote is not common in our samples. It is almost absent in the Tertiary sediments, which may be a consequence of either no supply from the source area, or weathering in a fairly acid environment (pH 5.5—6, Jeffries & White 1940, Bakker 1957b).

The results of the countings of each sample have been grouped into three parts. The first group gives the resistant minerals (*D*), with percentages of 50 % or more. Other symbols can be added, namely *T*, meaning tourmaline, over 15 %, and *T'* if it is over 50 %; *Z* zircon over 15 %, *Z'* when over 50 %; and *R* rutile over 15 %, *R'* when over 25 %. The second group indicates by means of symbols the minerals which are not abundant, but often present in a greater quantity. The following symbols have been used: *G* garnet over 10 %, *G'* when over 20 %; *Al* alterite the same. The metamorphic mineral group taken together is indicated by *M*, when over 10 %, by *M'* when over 20 %; *s* has been added for staurolite over 5 %, *s'* over 10 %, and *a* for andalusite, *d* for kyanite, *si* for sillimanite as grains, *f* for sillimanite as fibrolites. The samples of the river terraces all contain a small amount of epidote. For these samples the symbol *E* in the second group shows the presence of this mineral. Finally the third group indicates other minerals, if they are present in 4 per cent or more. In this group *To* means topaz, *A* anatase, *B* brookite, *E* epidote when not in terrace samples, *Ab* amphibole, *P* pyroxene and *K* corundum. Examples are given in table XIII.

Grain size variations

First, the variations in composition of the heavy fraction, sofar as due to differences in grain size, have to be considered. From a number of representative samples the grain size distribution of the heavy separates was

TABLE XIII.

Examples of heavy mineral groups.

	opaque	tourmaline	zircon	rutile	resistant minerals	garnet	alterite	staurolite	kyanite	andalusite	sillimanite	fibrolite	metamorphic minerals	anatase	brookite	epidote	glaucophane	augite	hypersthene	topaz	type
1-002	50	10	35	10	55	9	10	8	8				16	3	1	5				1	DZ - EMsd
1-076	30	22	24	9	55	20	6	9	2		1		12	1		5	1				DTZ - GMs - E
2-044	13	51	6	10	67	6	3	7	1	11	2		21			2				1	DT′ - M′sa′
2-066	21	45	20	9	74	3	4	8	3	2	1	1	15		4						DTZ - Ms - B
3-006	14	46	17	9	72	5	4	5	1	8			14		1			2	1	1	DTZ - Ma
3-060	23	21	50	21	92		3	3		1			4				1				DTZR

determined. Four of them are presented in fig. 39. Many samples do not contain a considerable coarse fraction, and it is therefore rather difficult to obtain a slide with a sufficient number of coarse grains for a count. The coarsest fraction, 420—300 microns, is too small to be of any use. Two of the samples mentioned do not even contain a single mineral in that size class.

Sample 1-005, a typical example of a river terrace sediment, shows in the coarse size class only tourmaline and metamorphic minerals. Coming to the finer fractions, these two components decrease. Two other minerals, rutile and zircon, appear and steadily increase in number. The finest size class almost entirely contains the latter components.

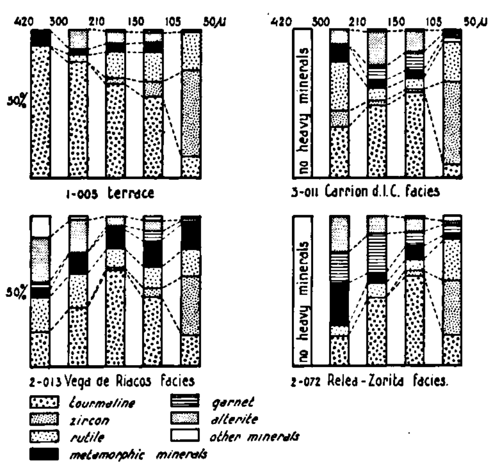

Fig. 39. Distribution of heavy minerals in various grain size fractions of some samples.

The other samples show more different heavy mineral species, even in their coarse sizes. The general tendency is a tourmaline content with a maximum in the middle sizes, a zircon and rutile content with a maximum in the finest fractions, a decreasing metamorphic mineral content from coarse to fine, and the same for garnet and alterite when present.

Whereas the fine grained sediments provide a small number of heavy mineral grains, the respective fractions 50—35 microns of some samples have also been studied. This size class only contains zircon and rutile grains. A further consideration of this fraction would thus increase the common mineral percentage and not bring changes in the association.

Heavy mineral associations in the Tertiary sediments

Fig. 40 represents the various Tertiary facies with their heavy mineral associations. Three groups of minerals can be distinguished in the histograms, namely that of resistant minerals, that of metamorphic minerals and that of other minerals. Table XIVa gives the percentages of some representative samples from the different groups.

The figure gives the general impression that in the area two associations can be distinguished, one in the north-eastern part having a high tourmaline content and a moderate number of metamorphic minerals, chiefly staurolite.

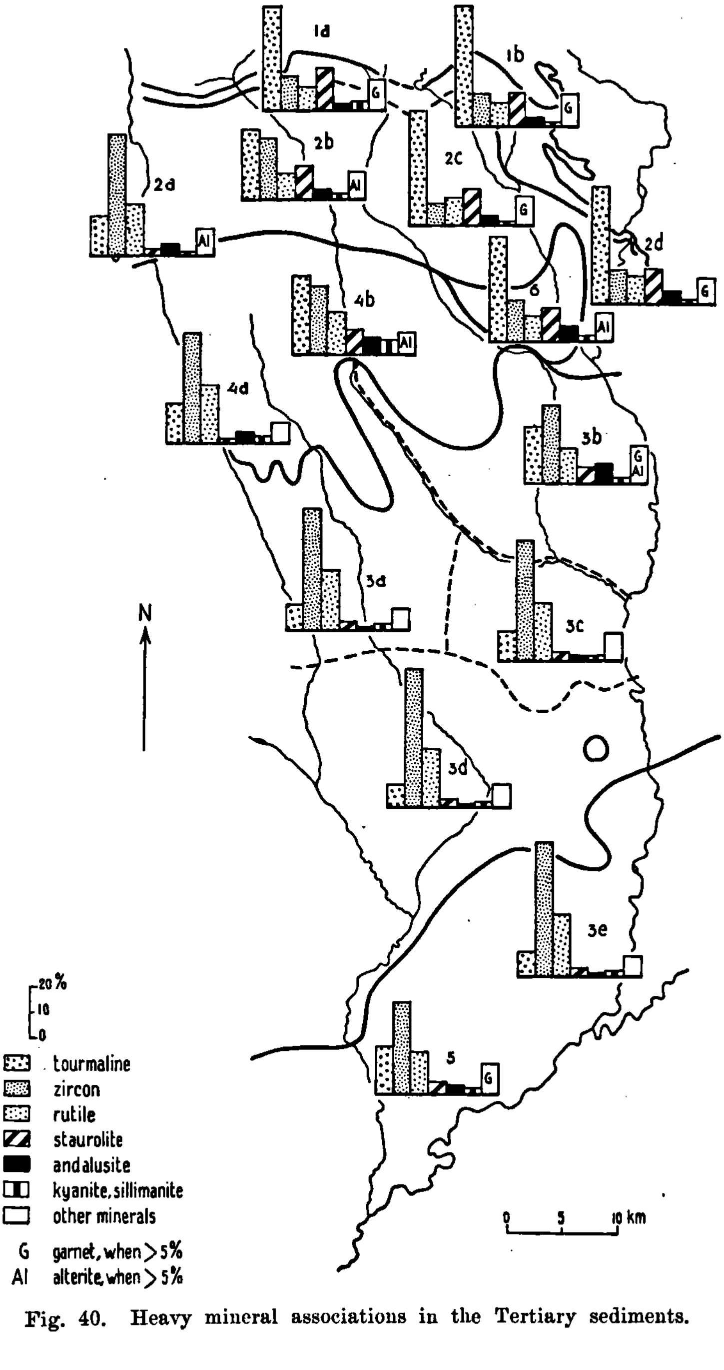

Fig. 40. Heavy mineral associations in the Tertiary sediments.

This may be called the tourmaline-staurolite-association (*TS*-association). The other association, found in the eastern and southern part of the investigated area, is defined by a great percentage, even up to, or over 50 %, of zircon, and a rather high rutile content. This has been called the zircon-rutile-association (*ZR*-association). Between these two areas a mixed zone can be found, the *X*-association.

The boundaries of the areas of the mineral associations do not coincide with those of the different facies, which have been defined by other, chiefly field criteria. The TS-association can be found in the sediments having the Cuevas facies (1), the eastern part of those having the Vega de Riacos facies (2) and the Zorita facies (6). The ZR-assoziation extends from the Vega de Riacos facies at the river Carrión, the Relea facies (4) and the Carrión de los Condes facies (3) through the campiña towards the páramo region (5). The X-association lies in three different facies areas, namely that of Vega de Riacos, that of Carrión de los Condes, and that of Relea.

The entire distribution, with a probable exception of the most northern part of the ZR-association, histogram 2a, might be due to differences in grain size. Indeed, from the NE, where the Cantabrian Mountains are lying, towards the SW with its so-called "true" basin sediments, there is a general tendency towards a decreasing grain size, as is shown by the grain size analyses, which coincides with a rapidly decreasing tourmaline-staurolite ratio and an increasing zircon-rutile content. A NE—SW direction of supply would therefore seem to be apparent.

However, the morphological investigations (see chapter IX, and Nossin 1959) show a drainage direction from NW to SE in Tertiary times, and even later. Also the pebble analyses (roundness, pebble composition) give a main direction from NW to SE (see chapter VI). Grain size in the Vega de Riacos facies also decreases from NW to SE, and the heavy mineral supply must also have been from NW. This means that the transition from the TS-association to the ZR-association in a southwesterly direction is not caused by a decrease in grain size of the sediments. The coincidence with the grain size distribution is purely incidental.

Nossin found that the metamorphic mineral group came chiefly from the Mesozoic sediments, exposed, as has been stated earlier, along the southern border of the Sierra del Brezo and in the whole region E of this mountain chain. The Palaeozoic mountains in the W, on the other hand, have a rather poor association, mainly of resistant minerals (see table XIVb for some representative samples). This difference is partly reflected in the basin sediments. The western half of the area, drained by the rivers Carrión and Valdavia, is characterized by the Palaeozoic association with only very little admixture of the Mesozoic association, whereas in the eastern half, around the river Pisuerga, the heavy minerals can all be correlated with those of the Mesozoic sediments.

The heavy minerals of the sediments in Cuevas facies with its coarse detritus near the border are mainly determined by those of the Mesozoic limestones. In the W the matrix of the limestone conglomerate has a TS-association, type *DT-M's'* (histogram 1a in the figure). In the E the association is the same, but of a *DT-Ms'*-type (histogram 1b). The sediments are chiefly coarse conglomerates and sandstones with a coarse matrix, so that the samples carry abundant tourmaline and metamorphic minerals, mainly staurolite.

TABLE XIV.

Some representative heavy mineral counts.
A. Average samples of each association within the Tertiary deposits;
B. Some samples from the source area (after Nossin 1959);
C. Average samples of river terrace deposits.

			opaque	tourmaline	zircon	garnet colourless-pink	garnet red-brown	rutile	anatase	brookite	titanite	staurolite	kyanite	andalusite	sillimanite grain	sillimanite fibrolite	epidote	alterite	hornblende	glaucophane	augite	hypersthene	topaz	chlorite
A	2-016	region 1	20	45	15	6		10				16	1	4				3						
	3-059	2a	23	15	44			21				4	1	3	1		2	8	1					
	3-054	2b	30	25	31			11				12	2	2		1	1	12	3					
	2-036	2cd	15	48	8	7		10		1		16	1	3				5					1	
	5-067	3ac	23	10	46	2	1	24				5	1	2			2	6					1	
	3-011	3b	15	22	30	8	2	12		2		5	1	9	1			6				1	1	
	6-015	3de	24	10	52	1		25	1			4	1	1			1	4						
	3-066	4a	28	12	45			27		1		1	3	7			1	3						
	4-008	4b	26	13	24	2		17		1		8	3	7	1		1	6						
	5-007	5	14	19	33	2	2	21		1		8	3	5			2	4						
	2-078	6	26	37	19	5		9				12	2	11			2	3						
B	Carboniferous (Curavacas congl.)		34	6	38	5		25	2							2		19			1			1
	Wealden		nd	51	37			7	2			1					1	1						
	Trias		nd	41	20	2		4		1		31			×			1						
C	1-008	Rio Boedo	45	22	25	8		16	2	2		4	3				4	14						
	1-056	Pisuerga	30	38	18	4	2	13	1			10	4				4	5			1			
	1-081	Carrión	26	15	46	2	1	20				3	3	5			4	1						

The red beds in the Vega de Riacos facies have in the coarse sediments of the western exposures a heavy mineral composition, consisting of small zircon and rutile grains, as shown by the histogram (2a) of Villalba de Guardo. Eastward, though the sediments become finer grained, the coarse tourmalines and staurolites become abundant. The E had a supply almost only from the Mesozoic and shows a TS-association (types *DT-M's'*, (2c) and *DT-Ms'* (2d)), whereas the W was supplied from the Palaeozoic rocks, as shown by a ZR-association (type *DTZR,* (2a)). The central part was strongly influenced by both source areas and so has an X-association (type *DTZ-M's'-others* (2b)).

The Carrión de los Condes facies, extending over a wide area, has only one area with an X-association (type *DTZR-Msa* (3b)) in the E near the river Pisuerga. All the remainder shows a ZR-association (histograms 3a and c—e), also in the páramo region, the type passing from *DZR* (3a) to *DZ'R'* (3e). All influence of the Mesozoic sediments has disappeared here. Only at a short distance from the N, some slight influence can still be detected in the histogram 3b.

The two facies of Relea and Zorita again show features similar to those of the Vega de Riacos facies. The W (4a) has a ZR-association, type *DZR-Ma,* because only small quantities of metamorphic minerals and tourmaline are present. The centre has an X-association (4b) type *DTZR-Msa,* indicating a greater influence of the Mesozoic strip S of the Sierra del Brezo. The E, in the facies of Zorita, lying very near the border of the Mesozoic, shows a full TS-association (6), type *DTZ-M's'a,* even in its rather fine sediments.

Somewhat aberrant is the histogram of the sediments in the Páramo facies. Here it was very difficult to obtain slides with enough grains to make representative counts. Only some sandy marls, marls and limey marls gave, after treating a lot of material, a rather good heavy separate. Thus an average histogram (5) could finally be composed. The association does not belong to either of the associations occurring more to the N: it is neither a ZR-association, nor a TS-association, nor even an X-association. The type may be defined as *DTZR-Msa-others(G),* which we will call the *P*-association. It shows, besides an abundance of zircon, high quantities of tourmaline and rutile and rather large amounts of staurolite, andalusite and garnet. From which region the various non-resistant minerals have been supplied, is not certain. From the situation of the Páramos-limestones and gypseous marls in the south-eastern part of the Duero basin we suspect a supply from the Iberian Range with its Mesozoic limestones, but until now detailed sedimentological studies about these regions do not yet exist. A later investigation of this part of the Duero basin may possibly solve the problem.

When in the histograms one mineral type occurs in 5 per cent or more within the group of other minerals, this was mentioned by adding a symbol in the respective column. Only garnet (*G*) and alterite (*Al*) show this phenomenon. Apart from the histogram of the Páramos facies, garnet is present only in the NE, in the coarse sediments. It seems to have been supplied from the Mesozoic, although the data of table XIVb (after Nossin) do not indicate an important garnet content in Mesozoic formations. Only Kanis (1956) mentions the presence of much garnet in the small intrusive rocks exposed in the area investigated by him. As garnet is rather resistant to abrasion, such grains might be transported over a long distance, and thus be sedimented in the basin deposits.

Alterite, on the contrary, apparently originated from coarse grained

Palaeozoic rocks. Therefore, the occurence of a considerable quantity of this mineral in the western histograms of the Vega de Riacos facies, in the X-association histograms of the Relea facies and in the Zorita facies is easily explained. In the other histograms garnet and alterite also form the greater part of the group of other minerals, but their quantities are below 5 % and so they have not been mentioned separately.

Heavy mineral associations in the Quaternary sediments

The more recent sediments, namely those of the river terraces and those of the pediments, do not show great differences. Due to the fact that nearly all coarse terrace sediments could be classified in the silty sand-sector of the Shepard-diagram, a high content of tourmaline is common. Through the whole of the area the slowly southward decrease of grain size causes a decreasing number of tourmalines, and consequently an increasing zircon-rutile content. The different terrace levels all give the same results, so that it was not necessary to draw a map; table XIVc represents an average sample of a terrace of each river. The Pisuerga, coming from the Mesozoic region in the E, supplied more metamorphic minerals than e. g. the Carrión, which originates in Palaeozoic rocks. The terraces of the rivers Boedo and Valdavia owe their existence to a former course of the Pisuerga in ancient Quaternary times, which course also came partly from the Palaeozoic region. A typical mineral of the terrace sediments is epidote, which occurs in small amounts, but is nearly always present. This may be due to a preservation of this mineral, which in older deposits could have disappeared. As to the heavy minerals, it is the only difference between the terrace deposits and the Tertiary sediments (see p. ...).

The coarse pediment debris, where they have a sand size content sufficient to give a heavy separate, do not show any proper character. Because they are all mixed with the underlying older deposits, they contain the same heavy mineral association as these underlying sediments.

Final remarks

To summarize it can be said that the differences in the heavy mineral composition are small. The associations do not coincide with the boundaries of the facies as determined in the field. The group of resistant minerals dominates the associations. The distribution of the TS- and ZR- heavy mineral associations is not determined by the decreasing grain size of the sediments, but by the supply areas.

2. LIGHT MINERALS

Introduction, method of investigation

The study of the light minerals, that is the fraction which, after the separation by bromoform, remains floating on the surface of the heavy liquid, may help to give a better insight into the source area of the basin sediments. Only the quartz-feldspar ratio has been estimated. Micas have never been found, either in the heavy, or in the light separate, but some may have dissolved during the preliminary treatment.

The distinction between quartz and feldspars was the main problem in the identification. Several methods have been tried out. (1) The method of determination of the refractive index has the disadvantage that oligoclase and andesine cannot be distinguished from quartz, these minerals having refractive indices lying too close together. (2) Cleavage of the feldspars is another means of identification. (3) Twinning often cannot be seen because of the minerals lying on their (010)-plane. (4) Staining with malachite green, after preliminary treatment with HF, seems to be the best method, but is rather difficult to carry out on grains. Therefore, we selected the method of determination of refractive indices, sometimes together with determination of cleavage.

The samples were obtained during the preparation of the heavy mineral fraction, as described in part 1 of this chapter. The separates of light grains dried by alcohol have been investigated according to the refractive index method as developed by Schroeder van der Kolk. The use of chloro-benzene, with a R. I. = 1.526, was applied by Alexanian, Rouge & Vatan (1954). By this means only quartz ($n_\omega = 1.545$, $n_\varepsilon = 1.553$) can be distinguished from the feldspars with a low R. I. The feldspars with higher refractive indices have been determined by means of nitro-benzene (R. I. = 1.553). This method cannot, therefore, provide the distinction of all feldspars from quartz.

Mineral description, comparison with other studies

It first had to be known which feldspars could have been provided by the source area. It so happens that the sediments found in the Cantabrian Mountains are poor in feldspar, but a few small intrusives (Kanis 1956) could have provided some feldspar with both R. I.'s higher and lower than that of quartz. A high feldspar supply into the basin sediments did not occur.

Among the feldspars only those with a R. I. lower than that of quartz have been found, for as all clear grains, immersed in nitro-benzene, show their refractive indices to be lower than that of the liquid. Feldspars with a R. I. higher than that of quartz were never seen, and must either have disappeared during transport, or their source rocks were not yet exposed in Tertiary times.

The light mineral separates also contain troubled grains with corroded surfaces, which seem to be saussurites (alteration products of feldspars and some other minerals). They remain greyish, and do not show any colouring. Their R. I. is often higher than that of chloro-benzene, but sometimes lower; the opposite can be said of their R. I. in nitro-benzene. The majority has a R. I. nearly equal to that of quartz. Vatan (various recent papers) calls such minerals *alterites,* but this name has already been used for strongly altered heavy minerals (van Andel 1950). Thus another name has to be found. A suitable one seems to us *light alterites.* These altered minerals often occur particularly in the fine fractions of the light separate, but they are also present among the coarser sizes. However, not all fine deposits show a great content of light alterites, and so the presence of this mineral does not depend on the grain size distribution.

Only a few studies on the distribution of light minerals have been published. The best known are those made on river sands, for instance Russell's on the Mississippi (1937), and that on the Rhine by Koldewijn (1955). However, these investigators worked with the staining method or with the universal stage method respectively, which in our case has not been used.

In the work on the Rhine sands, the quartz has been divided into white quartz, pink quartz, and quartz aggregates; these pink quartz and the aggregates have been determined by means of the binocular. In our samples they have only rarely been found, that is in percentages of 0—5 % of all quartz particles, and therefore are not significant for the light mineral associations.

The majority of the quartz grains consists of very clear, white to colourless, particles.

The light alterites of the investigated area, under a binocular, show a yellowish-white colour, do not reflect the light, and are not transculent or transparent.

Associations in the Tertiary sediments

The monotony of the light mineral associations is also evident. As the source rocks did not provide much feldspar, quartz has been supplied almost exclusively. A loss of feldspar through attrition during the transport may also have occurred, although the process is very slow, sometimes even negligible (Koldewijn 1955). The rate of loss in a warm and humid climate may be somewhat greater, but in such climates hardly any feldspar comes into the rivers (Bakker 1957a), even when feldspar-rich rocks are present. In other climates also the relief in the source area is important for feldspar supply. The stronger the relief, and the more rapid the erosion, the less is the destruction of the feldspars before arriving at the place of deposition. Sandstones sedimented during or just after an important tectonic uplift may be expected to contain many feldspars.

Fig. 41 presents the light mineral distribution within the various Tertiary facies. Only the percentages of feldspars and of light alterites are given, as the rest always consists of quartz. The feldspar content in all deposits varies between 2 and 4 per cent, the sediments in the Carrión de los Condes facies generally having the lower percentages. Thus, neither changes of climate, nor a higher or lower relief in the Cantabrian Mountains are reflected in the feldspar content of the various sediments.

It is not known, to which degree the light alterite content of the light separate allows drawing conclusions. These minerals have the same aspect as the saussurites of the heavy fractions. It is unknown whether they are alteration products already present in the source rocks, or have been altered during transport or even after deposition. It is striking that the light alterites occur in great amount in the sediments in two facies only, viz. the Carrión de los Condes facies, except where this facies extends into the páramo region, and the Relea facies, but not in the contemporaneous Zorita facies. As has been pointed out, the fine-grained character of a sediment does not imply that it has a great percentage of this mineral, and indeed the percentages of light alterites in the páramo region (3e) of the deposits in Carrión facies, and the deposits in Zorita facies, is very low. The rather low content of light alterites in the E, that is in the 3b and 3c regions, of the Carrión facies may be due to a supply from other directions, namely from the Mesozoic deposits, which will thus contain only small quantities of light alterites. The main supply of these minerals in the Carrión de los Condes facies must have come from the NW, that is, where Palaeozoic source rocks are exposed. Various Palaeozoic so-called subgraywackes indeed contain a rather great percentage of light alterite grains, and hardly any feldspar. Only the almost total absence of light alterites in the 3e sediments of the páramo region remains unexplained. Whether they disappeared in solutions which come down from the overlying gypseous marls and limestones, or have been absent from the beginning owing to a supply from another direction, for instance from the Mesozoic of the Iberian Mountains, cannot be ascertained.

The only other investigation of the light mineral content of Tertiary basin

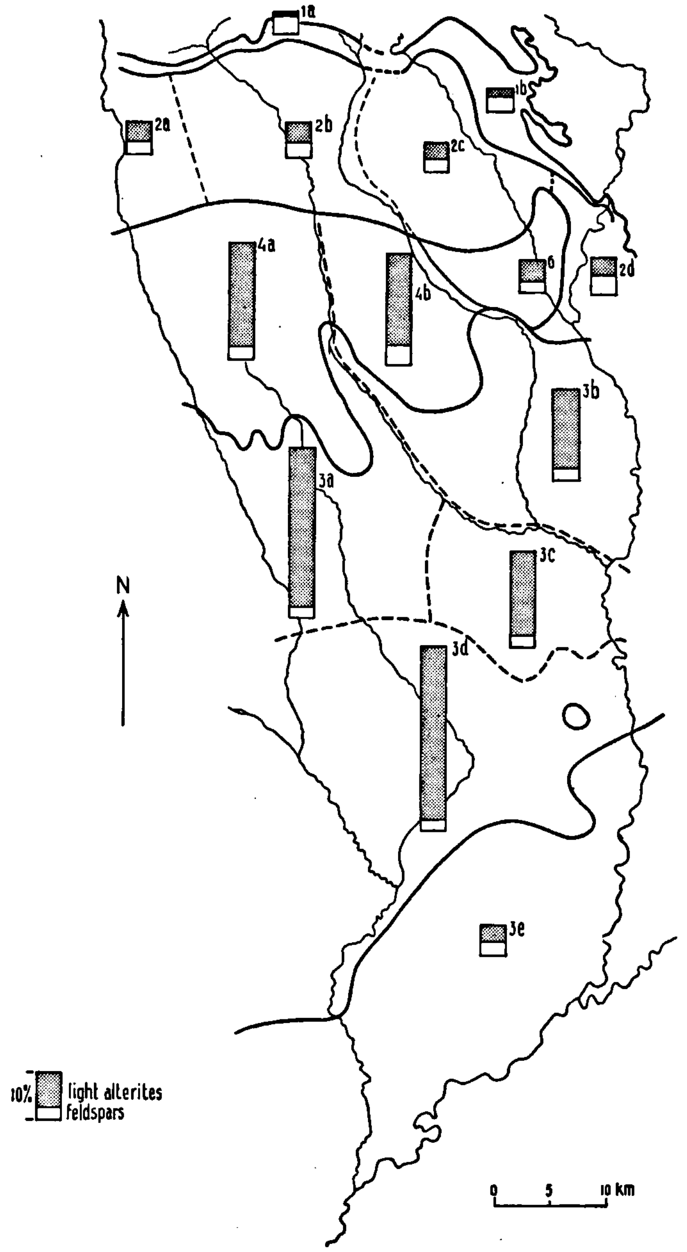

Fig. 41. Light mineral associations in the Tertiary sediments.

sediments in Spain is that by Riba (1955a), who studied the western end of the Ebro basin, north of the Iberian Mountains. In this region also quartz is the most abundant mineral present. Feldspars and light alterites together form an average percentage of 5, which indicates that the source area, i. e. the Cordillera Iberica, does not contain feldspar-rich rocks. Future studies in sediments in the S of the Duero basin, and in the NW of the Tajo basin, where the source area, the Cordillera Central, chiefly consists of igneous rocks, might provide better results on the behaviour of feldspars.

Associations in the Quaternary sediments

The light mineral associations of the Quaternary deposits show a greater monotony, even than those of the Tertiary deposits. A 100 % quartz content is common, and therefore the results have not been presented in a figure. The sediments of the raña of Guardo, being partly derived from the subsoil, have not been analyzed. The mixed terrace deposits show a higher content of light alterites, derived from the underlying sediments, chiefly from those in the Carrión de los Condes facies. The mixed types of the river Carrión have the highest percentage of light alterites in the region where the yellow beds in the Carrión facies are exposed. In the north they have less light alterites, which is in accordance with the underlying Vega de Riacos and Relea facies. The same may be said of the Pisuerga terrace sediments. Where this river passes through sediments in Vega de Riacos and Zorita facies, hardly any light alterite is present. More to the S in the Carrión facies these grains become more abundant, but their percentage remains lower than in the Carrión terraces. In the páramo region the light alterite content of the mixed deposits of both rivers becomes lower again.

Conclusions

It may be said that the light mineral associations of Tertiary and Quaternary sediments in this region have no importance in determining source areas and palaeoclimates. So long as the mineral composition of the rocks in the source area is not yet known, no conclusions on the content of light alterites can be drawn.

3. CLAY MINERALS

Preparation of the clay size fraction

The following method developed by Favejee was employed. A certain amount of a sample, depending from its clay size content, was first treated with H_2O_2 6 % and HCl (endconcentration ± 0.2 N) in order to remove organic matter, carbonates, etc. Then it was washed with 0.01 N HCl on centrifuging. Iron oxides were not removed. Wet sieved through a 105μ -screen the sample was allowed to settle its fractions coarser than 1 micron in a NaOH solution, or when the sample contained a low clay size percentage its fractions coarser than 2 microns. The siphoned clay size fraction could be precipitated in an acetic acid-calcium acetate solution. In the centrifuge the separate was washed out, first with aqua dest., and afterwards with alcohol. The dried sample could be used for further investigation.

Method of investigation

X-ray diagrams have been used for the clay mineral study. The *x*-ray films were made with the Guinier camera, using CuKα radiation, 35 kV, 15 ma, with an exposure time of 5 hours. The interpretations are of Mr. Th. Levelt, assistant of the Physical Geographical Laboratory of the University of

Amsterdam, who also emphasized that the percentages give only a rough picture of relative ratios.

Because the samples were not made free of iron oxide, many diagrams show the presence of goethite. This is especially the case with the samples having a red colour.

The coarser the clay size fraction used, the higher is the percentage of quartz found in the analysis. This percentage sometimes amounts up to 10 %.

Depositional environment

The application of clay minerals for the determination of source rocks and depositional environments of non-recent sediments still meets with difficulties. In recent sediments and in soils, at least the distribution of the various clay minerals is rather well known. Progress in clay mineralogy up to 1952 was summarized by Grim (1953), whose work served as a base for our interpretations.

Millot (1953) attempted to give a method for distinguishing between clay minerals derived from specific parent rocks, and clay minerals formed during and after deposition. He concluded that the inherited properties of a clay mineral are maintained if these are in equilibrium with the new environments, if not the clay is altered.

According to several investigators (e. g. Millot 1953, Rivière 1953) marine sediments should contain kaolinite and illite, those deposited in a more calcareous environment containing more illite. Sediments deposited in calcareous freshwater are illitic, sometimes with sepiolite and attapulgite, and those of acid freshwater are purely kaolinitic. Deposits from evaporating lagoons are purely montmorillonitic, and those from alkaline and soda lakes contain illite and montmorillonite. Bakker (personal communication) found in recent coastal sediments in Surinam, and in clay transported by the Caribbean Stream about 40—60 % of illite and montmorillonite in various ratios, and about 40 % kaolinite.

More recent studies give further information on the genesis of clay minerals. Important is the alteration of these minerals in soils, often depending from climatic conditions. Grim (1958) states that the greatest changes occur when the sediments enter into another environment. Later they only show a slow further gradual change. However, Weaver (1958) presumes that most clay minerals in sediments strongly reflect the character of the source rocks, and that depositional environments only slightly influenced them.

The solubility of SiO_2 increases with increasing pH-value. So in an alkaline environment clay minerals with a high SiO_2/Al_2O_3 ratio, and also illite, are formed, whereas in an acid environment clay minerals are formed with a lower SiO_2/Al_2O_3 ratio. Weathering in warm and humid tropical climates creates a rather acid environment, and favours the formation of kaolinite. Important is also the presence of alkalies, particularly potassium and magnesium, in the new environment. Potassium favours the formation of illite, magnesium that of montmorillonite. When illite is abundant in the source rocks, this mineral is also present in their soils, and in the sediments derived from them. It appears, therefore, that the agents which influence the clay mineral associations in sediments are very complex.

Soil formation is, in our opinion, more important for the variations in clay minerals than inheritance. But this latter factor may not be excluded, especially when soil formation only occurred during a short time.

Clay mineralogical studies in Spain have been mainly carried out on soils,

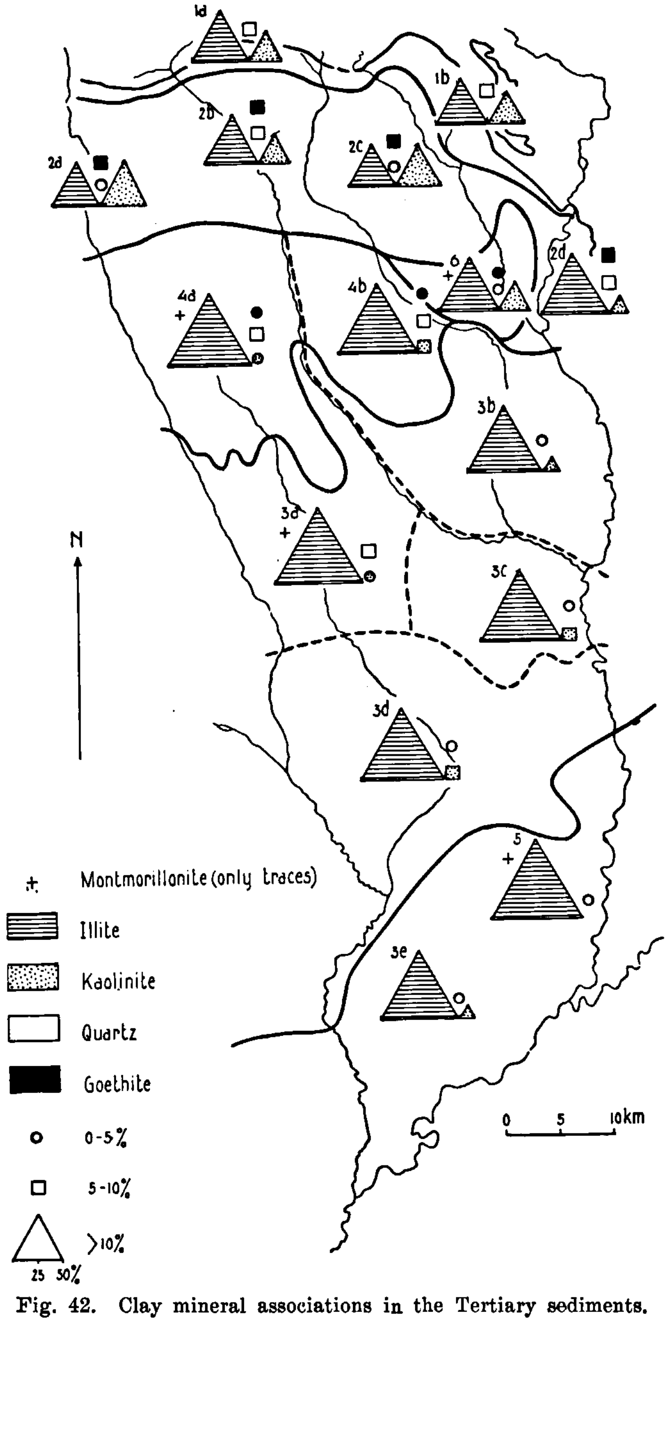

Fig. 42. Clay mineral associations in the Tertiary sediments.

and not on unweathered sediments (Albareda 1956). Muñoz Taboadela (1953), who started with typical Peninsular soils, such as the red calcareous soils of the arid zone, and the Mediterranean terra rossa, found that among the clay minerals illite dominates, and that some kaolinite is present. This is in good agreement with the clay mineral associations in the red deposits of the area investigated by us.

Figs. 42 and 43 present the distribution of the various clay minerals within the Tertiary and Quaternary sediments of the investigated area. It is apparent that illite is the most abundant clay mineral present. Kaolinite occurs only in some facies, and montmorillonite is almost absent. The percentages of quartz and goethite are also given. The pH-values of the samples could give some further help. Their possible relation with the occurence of different clay minerals will be mentioned in some cases, when describing the various facies.

Cuevas facies

The coarseness of the deposits in this facies, and accordingly the small clay content was a difficulty for obtaining a representative amount of clay for x-ray analysis. Only from a few samples a clay size fraction $< 2\ \mu$ could be taken.

The clay minerals within this facies (diagrams 1a and 1b, fig. 42) show a great quantity of illite (± 55 %), and also a considerable amount of kaolinite (± 35 %). pH varies between 7.5 and 8.5. The soils (diagram W, fig. 43) on the Cuevas facies deposits contain more illite (up to 70 %), and less kaolinite. The quartz percentages are rather high in all samples, because of their coarseness.

The rather high percentage of kaolinite in this alkaline environment and the red colour could point to a warm and rather humid climate. But the pebble analyses (chapter VI) indicate a warm and rather dry climate during deposition of the sediments in the Cuevas facies. The presence of kaolinite may, therefore, be due in this case either to later alterations, for instance at the time of deposition of the red beds, or to inheritance from the source, that is weathering products of Mesozoic marine and brackish water limestones which occur in the mountains, where a more humid climate could have prevailed.

Vega de Riacos facies

In the clay mineral compositions of the deposits two associations can be distinguished: (1) an association with almost as much illite as kaolinite (diagrams 2a and 2c, fig. 42), and (2) an association with 60—70 % illite and less kaolinite (diagrams 2b and 2d). All samples of the red beds contain a rather great percentage of goethite. Muñoz Taboadela (1953) found similar associations in other red deposits in Spain.

The Palaeozoic source rocks chiefly provided illite, which mineral is also abundant in the red beds. The deposition of these sediments must have occurred in a warm and humid monsoon climate, with a strong red weathering. Such an environment is favourable for the formation of kaolinite, which mineral therefore is also fairly abundant in the red beds. Jungerius (1959, p. 144) found similar features in the Rhaetic red clays of the Moutfort region in Luxemburg.

Later the deposits in the Vega de Riacos facies were partly cemented with calcite. The pH-values of most samples became high (7.5—9.0). Only the samples of diagram 2a, coming from the outcrop at Villalba de Guardo,

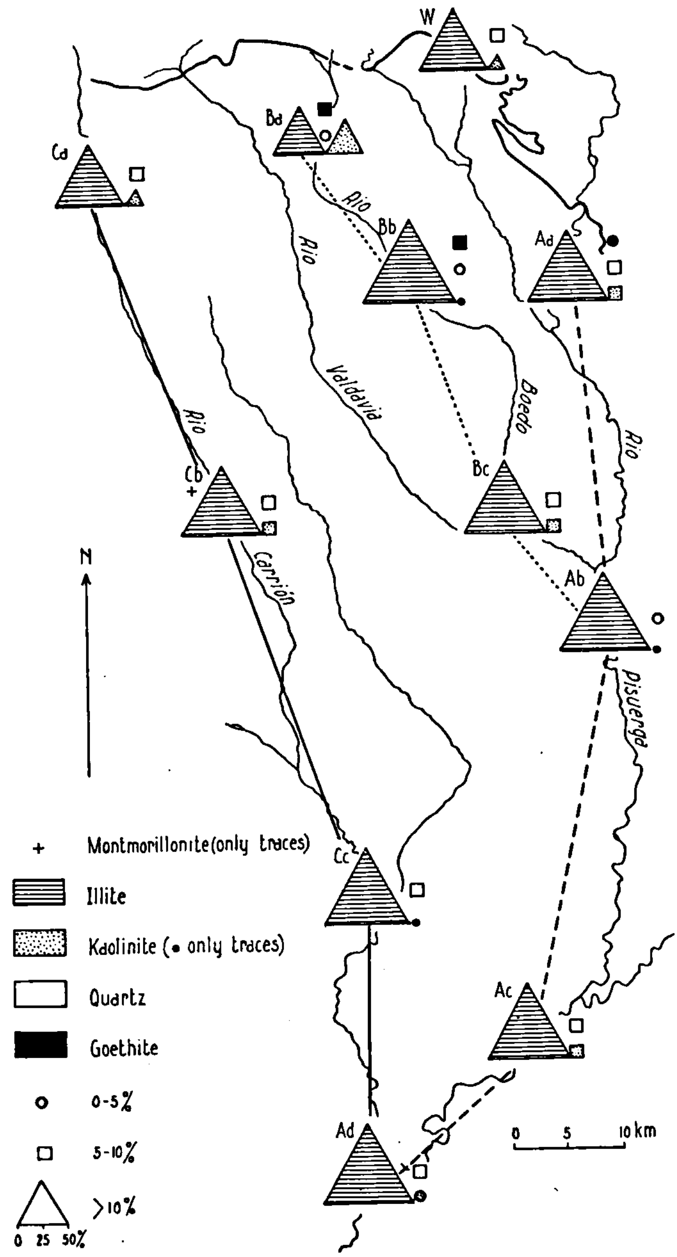

Fig. 43. Clay mineral associations in the Quaternary sediments.

mentioned various times, have low pH's (5.0—5.5, acid). This is caused by the presence of the thin lignite layer, which not only acidified its underlying deposits, but also changed their colour from red into white and grey. Here the circumstances are favourable for the formation of kaolinite, and indeed, this is one of the areas where kaolinite equals illite.

The other Tertiary facies

The great similarity of the associations within the Carrión de los Condes, Relea, and Páramos facies justifies to take them together for this purpose. All deposits contain 75—90 % illite, and only small amounts of kaolinite, except in the Zorita facies which has an average of 30 % kaolinite. In all these facies small traces of montmorillonite were occasionally found.

Illite is a mineral which is often representative for calcareous freshwater deposits, especially those of shallow temporary lakes (Millot 1953). So the abundance of illite in the Duero basin is easily understood. In this case much of this mineral will have come from the source area, and was deposited without having to undergo any change.

The deposits having Relea and Zorita facies which often are of red colour, show a determinable amount of goethite in the *x*-ray films. Kaolinite is almost absent in the upper beds, whereas it occurs in small percentages in the lower beds (in Carrión de los Condes facies).

The presence of montmorillonite in the few samples which could be obtained from the marly sediments in the Páramos facies, is in accordance with the opinions of this mineral being representative for an alkaline (saline) depositional environment. But it occurs in traces only.

The traces of this mineral in the sediments presenting the Carrión de los Condes facies and the Relea facies chiefly occur in those layers in which the lime crusts are found. So here it may be correlative with an occasionally arid environment, though it is possible that afterwards certain amounts of montmorillonite were transformed into illite. The pH-values of most sediments vary between 7 and 8.

The considerable amount of kaolinite in the red deposits in the Zorita facies may be explained in the same way as in the Vega de Riacos facies. The sediments in this Zorita facies have pH-values between 8 and 9, the alkalinity may be probably caused by later cementation.

Terrace sediments

The clay mineral composition in the various terrace sediments of the large rivers shows almost no differences (fig. 43). The source areas, in the W being mainly the Palaeozoic rocks, and in the E the Mesozoic rocks, provided the same minerals as they did in Tertiary times. The deposition by rapidly flowing rivers caused no important alterations. Mixing with the underlying sediments could only change the clay mineral percentages. The terrace deposits which lie on the Vega de Riacos facies sediments, therefore, show a higher kaolinite content than those lying on the sediments of the other Tertiaries. This is also reflected in the pH's of the terrace sediments, being nearly equal to those of the underlying deposits.

Conclusions

The clay mineral associations in the Carrión de los Condes, Relea, Zorita, and Páramos facies may confirm the results of other analyses, namely deposition in an alkaline freshwater environment, either fluvial, or sometimes in temporary shallow lakes (lagunas). Small traces of montmorillonite occur in the layers which are presumed to be deposits in a more or less saline environment.

The associations in the Cuevas and Vega de Riacos facies may be due partly to inheritance from the source area, and partly to alteration in a warm and humid monsoon climate during and after deposition. The illite content has increased where the physico-chemical conditions favoured the formation of this mineral.

CHAPTER IX

GEOMORPHOLOGY

Relief

The highest point of the investigated area is situated on the raña of Guardo, at 1207 m above datum level. The lowest point is the confluence of the rivers Pisuerga and Carrión, near Venta de Baños in the S of the area, at about 715 m. The investigated area is a part of a plateau occupying the Duero basin, and sloping slightly towards the W.

Within this area, with its simple lithology, and without tectonic structures except along the border, the strata show only little variation in consolidation and resistance to erosion. A simple morphology has developed, chiefly by fluviatile erosion. This landscape is typical of the Spanish Meseta.

In the south the Páramos-limestones, occupying a considerable area, form a high and strikingly flat level, called páramo. The rivers, where they have eroded through the resistant limestone, could rapidly develop deep and wide valleys in the underlying weak marls and clays. The slope angle varies between 20 and 40°. Where the upper limestones have disappeared by erosion the marls were rapidly carried away, and only a number of outliers of conical form, called oteros, were left, one of them being the famous Cerro del Cristo del Otero near Palencia town. Some typical erosion phenomena in the Páramos facies have been described by F. Hernández-Pacheco & Cesteros (1952), especially around the region of Tariego at the eastern valley slope of the river Pisuerga near Venta de Baños. Here a part of the Páramos-limestone complex slid down, but stuck halfway down the valley slope.

Where the Páramos-limestones are absent, the marls are absent as well. Here the surface consists of the underlying yellow sands and clays in Carrión de los Condes facies. These deposits form a lower level, though much less flat than that of the páramo. This lower level is in general called campiña, and in the province of Palencia preferably Tierra de Campos. The campiña level extends, as wide river valleys, in both a northern direction and southward into the páramos. The slopes of these valleys are called cuestas by the inhabitants.

Since most valley slopes are rather steep, and almost lacking in vegetation, the Tertiary sediments with their conspicuous colours are visible at many places along the slope. Destruction of the original vegetation, and ignorance of contour ploughing, caused deep gully erosion locally, especially in the unconsolidated yellow deposits in Carrión de los Condes facies, and more in the N also in the yellow and red deposits in Vega de Riacos and Relea/Zorita facies (photo IV). Sometimes it even develops a badland topography.

In the N of the investigated area the river valleys become narrower, and the campiña is absent. The higher level between the valleys is called here páramo too, because of its barren and desolate aspect, being only covered by heather and scrub. The "páramo" of Guardo is the most conspicuous part of this level. East of it, between the valleys of the rivers Valdavia and

Pisuerga, only some small outliers of the páramo-level remained, characterized by their flat tops and their cover of angular gravel (the Torcevela and Oteralbo hills). The surrounding upper terrace levels, however, are hardly less barren, and bear the same vegetation. Some other tops on interfluves are lower, and more rounded.

The investigated area thus includes a part of both the so-called gravel-páramo region, typical of the N and W of the Duero basin, and the limestone-páramo region, which characterizes the S and E regions of this basin. Fig. 44 shows a section through the whole of the investigated area.

Views on the history of the Duero basin

The investigated area has not been the subject of detailed geomorphological studies, but various works on the Duero basin as a whole, and on the surrounding mountains, also bear on our region. We have to mention particularly Stickel (1929), Vosseler (1931), Ed. Hernández-Pacheco (1934), and Schwenzner (1936). A summary has been given by Solé Sabarís (1952).

The Duero basin geologically forms part of the so-called Meseta block, which includes the Galician regions, the Castilian basins, and extends over Extremadura and the Sierra Morena. It consists of a basement of mainly igneous rocks and of Palaeozoic, folded during the Hercynian orogenesis. In Mesozoic times the Meseta block was strongly beveled to a surface sloping towards the E, where it was bordered by the ancient Thetys which at that time had its coast near the Iberian Mountains. During the phases of the Alpine orogenesis the bordering regions of the Meseta Continent became mountain chains, and parts of the Meseta, that is the former foreland, sunk down so as to become basins. The two basins, that of the Duero and that of the Tajo, are separated by an uplifted zone, the present Cordillera Central.

Schwenzner and Stickel were the first to make more or less detailed morphological studies in the Cordillera Central and in the Cordillera Cantabrica, respectively. More recent studies carried out by Solé Sabarís (1952), and by Birot & Solé Sabarís (1954b), conclude that the very complicated sequence of events, drawn up by Schwenzner, is not in accordance with the facts, and that the development of the basins and their surrounding mountains was more simple. Solé Sabarís gives the following simplified history of the Meseta:

(1) A folding during the Savian and Styrian phases. Formation of the folded borders of the Meseta, doming up of the Palaeozoic basement, and initial development of the Cordillera Central and the Castilian basins.

(2) Miocene sedimentation, covering the ancient relief, and terminated by the development of the initial erosion surface of the Meseta.

(3) Post-Pontian deformation of this surface, and renewed uplift of the mountains surrounding the basins, and of the Cordillera Central.

(4) New erosion cycle, formation of a pediment, and deposition of the rañas, in a warm and dry climate.

(5) Slight deformations during the Quaternary, and development of the river terraces.

We will examine how far this sequence of events is in accordance with what can be concluded from the sediments in the investigated area. The more recent history, as far as it can be deduced from the present topography and the sediments, will be treated in more detail for the area itself.

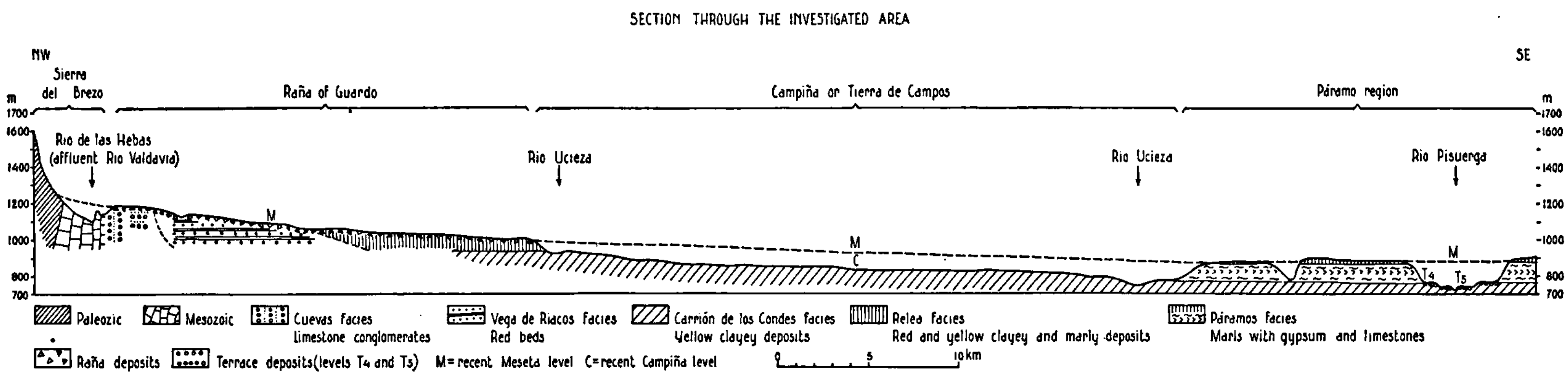

Fig. 44. Section through the investigated area.

Pre-Rhodanian history of the Duero basin

As has been stated before, we assumed the relation between Tertiary orogenetic phases and basin sedimentation to be as follows.

(1) The Pyrenean phase, which caused the deposition of the now steeply dipping, and overturned, limestone conglomerates.

(2) The Savian phase, during which the Mesozoic and Palaeogene deposits were steeply folded. After this the now horizontal limestone conglomerates were formed, mainly derived from the disintegrating Palaeogene conglomerates.

(3) A correlation of the later orogenetic phase with the Miocene deposits will now be attempted, taking into account the results of investigations in other mountain ranges surrounding the Duero basin.

The red beds of the Vega de Riacos facies, which are older than the yellow sediments of the Carrión de los Condes facies, must have been deposited disconformably on the nearly horizontal limestone conglomerates. The transition is so sudden that a continuous sedimentation seems very unlikely. Whether this disconformity is due to an uplift followed by beveling cannot be said. Tectonic movements during a Styrian phase, of which no evidence can be found in the Cantabrian Mountains, may have been the cause of the supply of the conglomerates having the Vega de Riacos facies, their red colour being a consequence of a climatic change at that moment.

According to Solé Sabarís prolonged erosion and denudation in the mountains and in the already deposited Tertiary sediments caused the formation of the so-called "initial erosion surface of the Meseta", no traces of which are seen in the mountains adjoining the investigated area. This surface must have been contemporaneous with the deposition of the sediments having the Carrión de los Condes facies. Meanwhile the climate changed, and the colour of the sediments became yellow. In the N of the investigated area the layers pass upward into those in Relea facies, and in the S into the gypseous marls and later into the Parámos-limestones. The change of sediment type is due to climatic changes and to stagnation of drainage.

The beveling during the deposition of the Páramos-limestones caused a rather flat surface in some of the surrounding mountains. In the Cordillera Iberica, for instance, the Páramos-limestones reach up into the mountains, and somewhat further into the interior of these mountains the same level is continued as a flat erosion surface (Richter & Teichmüller 1933).

The Cordillera Cantabrica, at the same time, did supply the more sandy deposits presenting the Relea facies in the western part of the investigated area. The more eastern part of the Cantabrian Mountains, consisting chiefly of Mesozoic limestones, meanwhile supplied the calcareous layers having the Zorita facies.

Late-Tertiary development

After deposition of the Páramos-limestones the Rhodanian orogenetic phase brought about important changes. The mountains surrounding the Duero basin rose up. This resulted in a strong dissection of the initial erosion surface of the Meseta, especially in the Cordillera Ibérica and the Cordillera Central. The basin itself only responded by slight undulations, even in the Páramos-limestones, though outside the investigated area. At this time the Duero basin was tilted towards the W, which caused a total change of the ancient drainage pattern. Before, this was directed towards the Mediterranean, as may also be concluded from the grain size distribution and pebble composition within the conglomerates in Vega de Riacos facies, but now the drainage was diverted towards the Atlantic Ocean. First the river Duero, and gradually all other rivers changed their courses, which process, as we will see, has not yet finished.

After the Rhodanian orogenetic phase strong beveling recommended, the development of the so-called Post-Pontian Meseta erosion level being the result (M-level in fig. 44). This level could obtain a great extent; as in many places it may be observed to pass from the upper beds of the basin sediments into the surrounding mountains. At the foot of the Cordillera Cantabrica this beveling caused the development of a large pediment, extending on the Cretaceous limestones too. For instance the Penilla hill, north of Castrejón de la Peña, and the Otero hill, west of Tarilonte, form part of it. Also more to the W the outliers of the Cretaceous sediments are capped by the same level, which was higher near the mountains than in the basin.

An interesting problem is the climate which must have ruled during the formation of the pediments. Generally the investigators think of an arid climate because sheetfloods, which are considered to have been the transporting media of the raña deposits, chiefly occur in such a climate.

The raña problem

The coarse, quartzitic raña gravels have been sedimented near the mountain foot. A supply mainly occurred through the valley of the river Carrión. More to the E, where the Mesozoic deposits are exposed, there was only a supply of fine-grained quartzitic detritus, brought from a greater distance by temporary rivers flowing towards the SE. This resulted in the deposition of rather fine quartzitic gravels, remains of which now can be found on the outliers, mounts Torcevela and Oteralbo.

Occasionally pebbles must have been transported farther into the interior of the basin, because on top of the Páramos-limestones at some places even great pebbles were found, as has been described in chapter VI. They lie at a higher level than the highest Quaternary terrace and therefore will probably be contemporaneous with the pediment debris.

On the raña problem a number of investigators have given their opinions. Oehme (1936) summarizes and discusses the papers published before. One of these, written by Casiano de Prado (1864), already contains the now generally accepted opinion on the genesis of the rañas, especially on their climate. Also Oehme admitted a genesis during an arid climate with accidental and heavy rains. The pebble and sand analysis, as carried out on the raña of Guardo (chapters VI & VII), confirm this origin. Oehme (1936, 1942), however, thought them to date from the Miocene, chiefly because he was not acquainted with later datings.

Birot & Solé Sabarís (1954a), treating the morphological development of the western borders of the Duero basin, mention the existence of the raña of Guardo, and admit a similar origin.

F. Hernández-Pacheco (1957) put the raña problem again under discussion, using new data, not only from the Iberian Peninsula, but also from the Sahara, where many investigations have been undertaken. The age of at least some of the rañas of the Iberian Peninsula has now been fixed as Villafranchian or a little older, because of their situation on marine deposits of the Late-Pliocene (see chapter III). The climate during the deposition must have been arid, with sheetfloods, a conclusion which now is no longer questioned.

The morphogenetical problem of the pediments found in arid and semi-arid climates, especially based on observations in Spain and North-Africa, has been treated by Mensching (1958). He not only discussed recent papers but also international terminology. He proposed the use of the term "glacis" for the "piedmont" plains which, in his opinion, were first formed during the Pliocene, and modified in the Quaternary. These glacis are typical morphological features found in regions which are now semi-arid. Their formation must, according to him, however, have taken place during savannah-climates with an alternation of moist and dry seasons, whereas the preservation, and the deposition of gravels, must be due to a more arid climate.

On the evidence of the data of our sedimentological analysis, and of previous literature, we think the following genesis, especially concerning the Pliocene bevelling and the formation of the raña of Guardo, to be the most likely.

(1) A change of climate, possibly already during the deposition of the Páramos-limestones, but mainly after it. This climate must have been less arid than before, tending towards a savannah-climate.

(2) A bevelling after the Rhodanian orogenetic phase. This bevelling formed the present Meseta-level, which extends along the mountain chains, as a pediment. This erosion cycle (formation of the M-level, fig. 44) is dated as Pliocene.

(3) Another change of climate, now tending towards a more arid character, but with very heavy seasonal rains. This change must have occurred during the Villafranchian. In this period the raña gravels were deposited. It does not seem likely that this climate can be correlated with the first Pluvial, as does Mensching.

Further Quaternary history of the investigated area

During the Rhodanian orogenetic phase the Duero basin was tilted towards the W, the direction of the river Duero being diverted towards the Atlantic Ocean. This caused the peculiar longitudinal profile of this river,

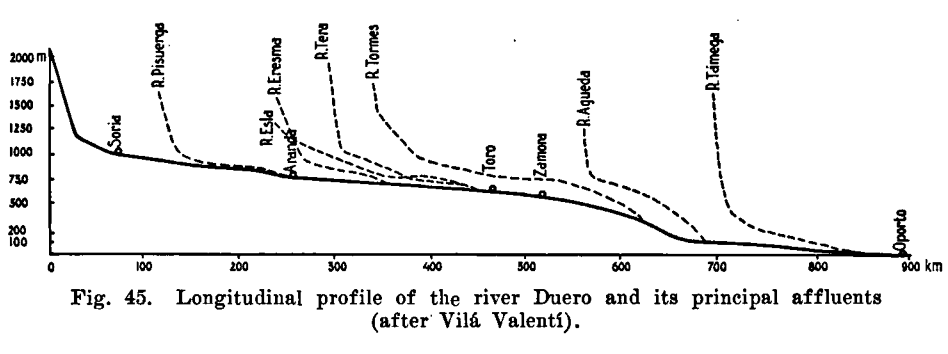

Fig. 45. Longitudinal profile of the river Duero and its principal affluents (after Vilá Valentí).

shown in fig. 45, together with those of a number of its important tributaries (after Vilá Valentí, in Solé Sabarís 1954). The low gradient of the Duero on the Meseta is striking (average fall 0.8 m/km). This part of the river through the basin is thus a so-called pseudo-lower course. The river leaves the basin, and at the same time the Spanish territory, through a narrow gorge. This part, together with the lower course in Portugal, has an average fall of 2 m/km.

The present direction of the Duero caused an adjustment of the directions of its affluents. As the Cordillera Cantabrica is situated at great distance from the basin centre, relicts of the ancient NW—SE drainage pattern may be expected. This is indeed the case in the investigated area.

As has been mentioned repeatedly before, the raña of Guardo gave rise to a diversion of the drainage pattern. The western side of the raña is therefore drained by small rivers flowing in a NE—SW direction, which are taken by the river Cea, an affluent of the river Esla. The Esla, at present, flows in a south-westerly direction towards the Duero. The rapid adjustment of the drainage to the new pattern in the region of León is easily understood because the region is situated near the lowest part of the Duero basin.

The eastern side of the raña has rivers flowing in a NW—SE direction, taken by the Valdavia. These rivers continue following older, Tertiary, directions.

Diversion of the river pattern. — The further Quarternary development of the relief in the investigated area is closely related to the changes in the river pattern. The present pattern is shown in fig. 46. The development of the upstream part within the Cantabrian Mountains, especially in the region with Mesozoic deposits, bordering the area investigated by us, has been analyzed by Nossin (1959).

The six major rivers crossing the investigated area are:

(1) the Pisuerga in the E, draining the eastern part of the Palaeozoic, and also the Mesozoic of the Cordillera Cantabrica;

(2) the Burejo, rather unimportant, which drains the region called Ojeda, between the present courses of the rivers Boedo and Pisuerga;

(3) the Boedo, a small river fed by the small quantity of water supplied by the southern slopes of the eastern part of the Sierra del Brezo;

(4) the Valdavia carrying off the water flowing from the southern slopes of the western part of the Sierra del Brezo, and taking most arroyos coming from the raña of Guardo;

(5) the Ucieza, also rather unimportant, but uniting the small arroyos which come from the south-eastern part of the raña;

(6) the Carrión in the W, coming from the Palaeozoic region in the Cordillera Cantabrica.

With the exception of the Pisuerga, the direction of flow of these rivers is chiefly NW—SE. Only the Pisuerga within the investigated area, has a N—S course at first, and later, after the confluence with the Arlanzón, becomes NE—SW, directed towards the Duero. However, the Pisuerga is bordered on its western side, that is in the investigated area, by the system with a NW—SE direction, mentioned just now, and on its eastern side by a region with rivers flowing NE—SW, coming partly from the Iberian Mountains.

The general diversion of the drainage towards the Atlantic Ocean has affected the region between the Carrión and the Pisuerga, causing a number of captures, which will be considered now. All must have taken place in Quaternary times, after the deposition of the raña of Guardo. With the exception of the three present rivers Carrión, Valdavia, and Pisuerga, all other rivers of to-day are unimportant, but they flow through wide valleys, too wide

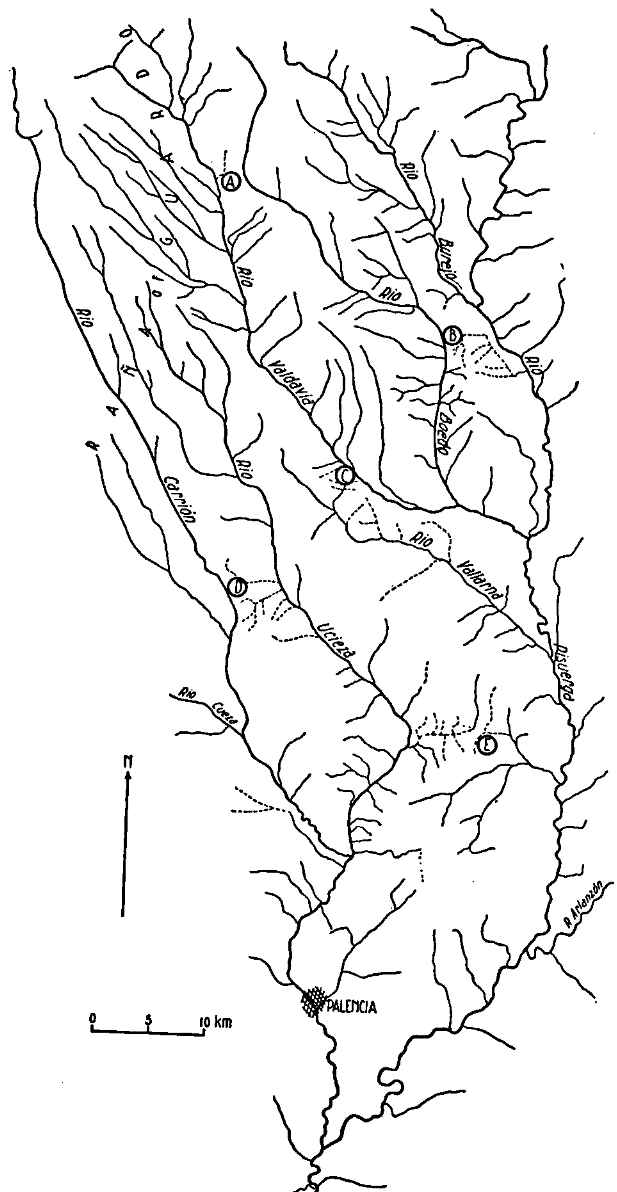

Fig. 46. Present drainage pattern of the investigated area.

to have been formed by such small streams. These valleys could only have been formed by powerful rivers which now have abandoned them.

At a glance five low passes (A—E), for which the term *gaps* will be used, occur in the divides, as can be observed on the map (fig. 46), that near point E being the most important. Some smaller captures may also have occurred, but we will attempt to reconstitute the history of only the five most important ones.

Three rivers, coming from the Cantabrian Mountains, flowed into the investigated area in Early-Quaternary times. They all had a long upper course through the mountain area. The first, in the W, is the river lying in the valley in which now runs the river Carrión. The second, in the middle, came through the so-called Brezo gate, connecting the upper course of the present Pisuerga with the wide valley of the present Boedo in the Meseta. The third, in the E, was a river through the gorge N of Alar del Rey, which valley is now occupied by the Pisuerga, but formerly by a river supplied by the water from the present rivers Rubagón and Camesa (Nossin 1959).

In the investigated area the western river passed through the centre of the raña, as does the present Carrión, but at its end it curved into the old NW—SE drainage direction. It must have passed along the gap near point D into the valley of the present Ucieza, in which the gravel of the former river is found. That the gravel could only be supplied by a powerful river, and not by an unimportant river as the Ucieza, can be concluded from the abundance of these pebbles, and their great size. This former powerful river will be called the High-Carrión. Where the Ucieza curves towards the SW, the gravels continue in a south-easterly direction along the gap near point E. From here the High-Carrión must have run through a valley torso in the páramo near Astudillo (the Astudillo gate) towards the valley of the present Pisuerga (fig. 46).

The course of the river which flowed through the Brezo gate can only be followed during the time of deposition of its T1-terrace. During this period it must have flowed until its confluence, near point A, with another river, as is demonstrated by the gravels lying in the wide and shallow valley of the present Boedo, to the far south-east. We will call this central river High-Pisuerga (see also Nossin).

The river entering by the E into the investigated area flowed steadily southward in the wide valley in which at present the Pisuerga is found. This eastern river will be called High-Camesa. It could never have followed a south-eastern course in old-Quaternary times, because of its taking up many eastern tributaries with a south-westerly direction.

Now that we have established the former courses of the main rivers, the former situation of some smaller rivers can also be reconstituted.

After the formation of the raña of Guardo, a number of rivers and arroyos at its eastern side flowed into a south-easterly direction. One river followed the northern part of the present Valdavia valley, along point A, where it united with the High-Pisuerga, the presence of many T1-terrace pebbles in the region, and the mixing with the raña pebbles being the proof. It continued through the middle part of the present Boedo valley, and along point B towards the present Pisuerga. This river will be called High-Valdavia.

Another river, flowing from the raña, more to the S than the High-Valdavia, is indicated in fig. 46. It occupied the valley part of the present Valdavia, directed NNW—SSE, passing along gap C, and went on into the direction of the present Pisuerga through the wide valley, now drained by an arroyo called

Rio Vallarna. In this wide valley many pebbles which came from the raña and from the T1-terrace deposits of the High-Pisuerga, can be found. The ancient stream may be called High-Vallarna.

In the southern section of the valley of the present Carrión running through the páramo region, a river must have flowed, supplied from the páramo region and form the Cueza drainage area outside the investigated area. This former river can be termed High-Cueza.

Evidently many rivers have changed their courses since the early Quaternary. The reconstructed courses of the six "high" rivers are summarized in fig. 47. This drainage pattern must have been present after the deposition of the raña, and before that of the T1-terraces.

Since the deposition of the oldest terrace sediments the captures must have occurred, caused chiefly by the adaptation of the old NW—SE drainage to the present NE—SW direction. From the heights of the gaps, relative to the various terrace levels, the age of the captures may be determined.

The High-Pusuerga changed its course after a capture within the mountain area, outside the investigated area, so that it had to leave the Brezo gate, as described by Nossin. This capture took place after deposition of the T1-terrace, now found S of the Brezo gate and in the valley of the Rio Boedo, and before deposition of the T2-terrace, which is found along the present course of the Rio Pisuerga.

The capture at A may have occurred at about the same time or a little earlier, the present Rio Valdavia flowing some 100 m below it, whereas the Rio Boedo flows only some 50 m below this gap. This is easy to understand, because these two captures occurred almost at the same time, leaving only an unimportant river Boedo in the wide valley.

At point B the change of the river must have occurred during the T2-terrace time, the divide lying at about 70 m above the Pisuerga.

The capture near point C indicates a change of the river course about during the T4-terrace time. The divide is not higher than some 40 m above the present Rio Valdavia. Behind this divide a tributary arroyo of the present Rio Vallarna originates at the same height and at a distance of only 1 km from the Valdavia.

As to the capture of the High-Carrión near gap D, the interfluve is somewhat higher than 30 m, so that this change of drainage pattern must have occurred just before the T4-terrace time.

The most important and conspicuous capture near point E must have taken place somewhat earlier than that of D. Possibly it was in the time of the T3-terrace. Remainders of interfluves have been found NW of Astudillo at a height of about 50 m above the present Pisuerga valley bottom. How far the terrace remainders of the T3-level, already described in chapter VI, may be brought in connection with the capture E, is treated in chapter X.

Formation of the campiña-level. — The campiña-level (C in fig. 44), which occupies the central part of the investigated area, varies in height between that of the T4- and T5-terraces, and is not so flat as the M-level on the páramos and the raña of Guardo. It is slightly undulating, being somewhat higher near the interfluves, and sloping towards the present river valleys. It must have got its present extension rather recently. The absence of any pebbles outside the present and former river valleys in the campiña is contrary to its having been formed as a plain with braiding rivers, and so its formation is due rather to denudation than to river erosion. Since the campiña is always found between

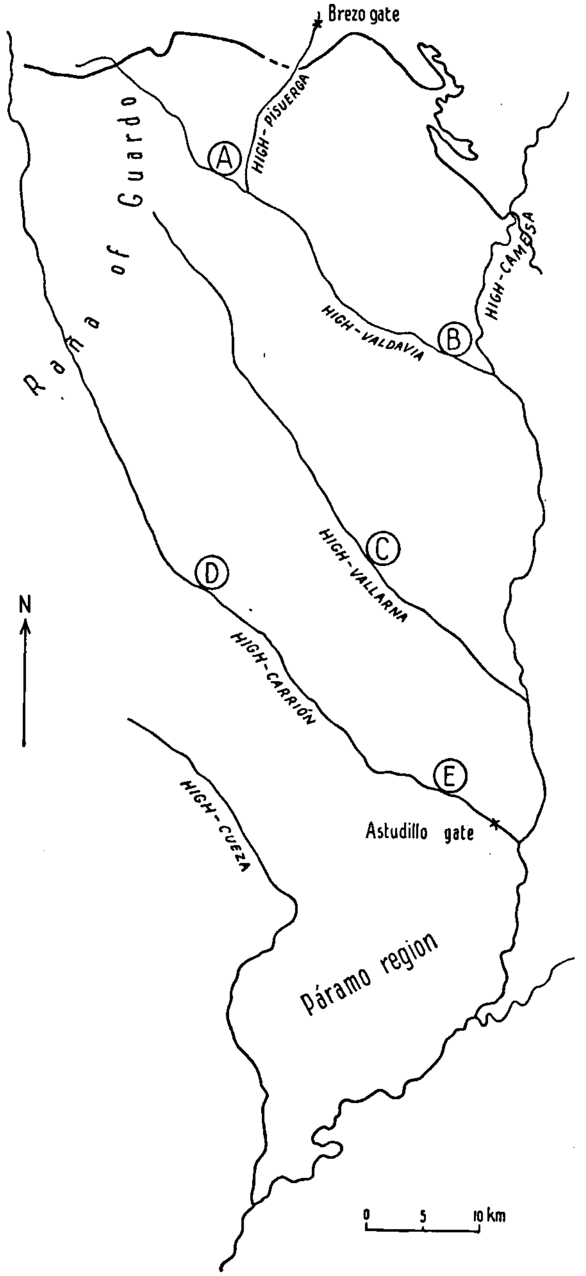

Fig. 47. Early-Quaternary courses of the most important rivers.

the limestone páramos, protected by their limestone cover and the so-called gravel páramos, lying against the mountain range, it may always have been a weaker zone where denudation could progress more rapidly. In the investigated area the most northern outliers of the limestone páramos are still situated at a distance of 7 km from the gravel páramo, so that a lateral transition cannot be observed.

Final remarks

In conclusion, it may be said that the sedimentological data agree with the simplified conception of the Tertiary development of the Meseta, as given by Solé Sabarís. The study of the raña of Guardo confirmed the present opinion as recently summarized by F. Hernández-Pacheco, except that an exact dating was not possible here. The river terraces, being the only evidences of the Quaternary changes of the climate in the investigated area, are an important help in the reconstitution of the relief development during the Pleistocene and Holocene.

CHAPTER X

RELIEF IN THE SOURCE AREA AND PALAEOCLIMATE

Introduction

In the preceding chapters many conclusions have already been drawn. In this chapter it will be attempted to give an outline of the palaeoclimate, and a correlation between the development of the Cordillera Cantabrica and the sedimentation in the investigated area as a part of the Duero basin.

Palaeoclimates can be reconstituted with the help of fauna and flora, of typical sediments such as red beds or evaporites, of pebble roundness and flatness, of the shape of sand grains, and of clay minerals. But generally not one of these features is in itself sufficient to determine a former climate beyond doubt, except in very evident cases, as for instance when the sediment is a glacial till. Taken together, however, the various methods can supply at least some indications on palaeoclimates.

In the investigated area various criteria for palaeoclimate are present. The palaeontological criteria have been taken from literature, and the sedimentological and geomorphological criteria follow from the investigation described in the foregoing chapters. An attempt will be made to deduce the most probable climate of each sedimentation period.

Correlations between the history of a mountain chain and the sedimentation in its foreland may be made by various methods. Pannekoek (1957) summarized and discussed several methods, especially those concerning pebble composition and lithofacies. The following review of the literature is partly condensed from his paper.

Heavy minerals of a foreland sediment give information on the rocks exposed in the source area at that time, and sometimes on the type of weathering in that area (Bakker 1957b). But often source rocks of different ages show the same composition in their heavy mineral content. Volcanism, for instance, creates favourable circumstances for heavy mineral studies, but when sediments become older, or when repeated redeposition occurs, only the most resistant heavy minerals remain (Pettijohn 1941).

Pebbles give better information on the rocks exposed in the source area. The principle was outlined, for instance, by Ampferer (1924) and Cadisch (1928), and received the name "inverse sedimentation" by Birot (1955). But generally not all species of rocks exposed at a particular time in the mountain area, are represented in the foreland deposits. As is the case with the heavy minerals, only the most resistant species will be preserved.

Lithofacies is another way of deducing the amount and kind of erosion in the source area. The method of the "correlated strata" was introduced by Oestreich (1899), worked out too rigidly by W. Penck (1924), and reduced to more normal proportions by Birot (1955). Coarse detritic clastics should be correlated with strong erosion and youthful relief in the source area. Clays, on the other hand, are often thought to represent lower relief, with rivers eroding the thick soil laterally, rather than cutting into the parent rock vertically. As erosion is often activated by tectonic uplift, coarse deposits have even been taken as an indication of tectonic activity, and the finer sediments of decreasing tectonic activity. Alternances of coarse and fine clastics have thus been correlated with rythmic uplifts in the source area. Birot, however, concluded that an alternation of sediments with different grain sizes is more strongly influenced by climatic circumstances, both in the source area and the area of deposition, than by tectonic movement. Bakker (1957a), for instance, found that in humid tropical regions finer sediments will be deposited almost exclusively, whatever the relief in the source area. The theory of correlated deposits, therefore, can only be applied with great caution. Comparisons with present basin sedimentation at the foot of a mountain chain are necessary. For the study of older foreland sedimentation fossil soil profiles may be helpful in determining former climates.

Light mineral studies show that, if feldspars are present in the source rocks, the feldspar content of clastic sediments is chiefly influenced by the palaeoclimate within the source area.

The study of the clay minerals is often a useful help for reconstitution of a palaeoclimate, and for determination of the source rocks of foreland deposits. Kaolinite, for instance, will be formed during weathering in a warm and humid climate, or in an acid environment. Illite, at contrary, is more indicative of an alkaline environment, and will often be inherited from source rocks.

The sediments found in the Duero basin reflect the climate during deposition more strongly than the relief of the source area.

Palaeogene and Miocene

Cuevas facies. — The conglomerates in the Cuevas facies contain practically nothing but pebbles supplied by the adjacent Mesozoic limestones, which fact is supported from the foraminifera within the pebbles. The great volume of the overturned conglomerates as appears from their thickness of more than 1000 m, is an indication that the Mesozoic sediments must have occupied a greater surface at that time. Palaeozoic pebbles are almost absent. The so-called *caliza de montaña* (Brezo-limestone) never supplied any pebble into gravel at all, so it is likely that no pebbles were found in the Palaeogene either. Only some quartzites are present in the limestone conglomerates, which proves that providers of quartzites, such as the Curavacas conglomerate, were exposed, though in a small amount.

The coarse deposits of the *grès de Las Bodas* (Ciry) will have been derived from the continental sediments of the Wealden, which contain so many small quartz pebbles, and which must also have been exposed at that time.

Indications on the climate may only be obtained from the pebble analyses, that is from roundness and flatness. The conglomerate is a mixture of two types of pebble, namely material locally supplied from slopes, and well-rounded material of fluviatile origin, deposited in a warm and rather dry climate. The grain size distribution, and the shape and roundness of the sand grains, show that we are dealing with a mountain foot debris, or at least a sediment transported over a very short distance. The heavy minerals have the same assemblage as those in the Mesozoic deposits; they faithfully reflect the source rocks, and demonstrate that the transport was short, the less resistant minerals still being present.

The relief of the Mesozoic source area could not have been very low. Even in a fairly dry and warm climate pebbles can only originate when there is a considerable vertical erosion. The deposition of these limestone conglomerates may therefore be correlative with a tectonic uplift, which we are inclined to attribute to the Pyrenean phase.

During and after the Savian phase, which folded the Mesozoic together with the Palaeogene sediments, important erosion caused the deposition of the almost horizontal limestone conglomerates. The thickness of these beds is not known. They have been supplied by the older limestone conglomerates, and by continued erosion of the Mesozoic limestones. According to the pebble roundness the climate was almost the same as that during the deposition of the older conglomerates. Here also Palaeozoic rocks are almost non-existent, and were probably exposed to a limited extent.

Vega de Riacos facies. — The sediments having the Vega de Riacos facies are the most interesting deposits of the whole investigated area, especially because of their striking red colour. Similar deposits have been found in other Spanish basins. Those of the western part of the Ebro basin were described by Riba (1955a).

All sedimentological investigations lead to the same conclusions on the climate during the deposition of the red beds. The red colour develops chiefly in a warm and humid climate, or in a climate with warm and wet summers; sand grain shape point to fluviatile deposits of a similar climate; and clay mineral associations do the same. Red beds are generally considered to be sediments of a tropical monsoon climate (Dunbar & Rodgers 1957), or to a climate with warm and wet summers, in which red-yellow podzolic weathering occurs (Krebs & Tedrow 1958). This conclusion may be also true of the red beds in the investigated area, but there are some indications that the climate already became drier, as may be concluded from the grain size distribution, and the presence of some small limestone pebbles in the conglomerates.

Similar deposits in the Ebro basin provided some fossil leafs of palm-trees, and contain intercalated thin gypsum layers, which should represent dry seasons (Riba). These data confirm the conclusions on the palaeoclimate at the time of deposition of the sediments in Vega de Riacos facies.

Another problem is the supply of the coarse pebbles in the red beds. They are mainly quartzites, but a few other species of pebbles are present. Most interesting is the presence of a very few, small, red, sandstone pebbles. According to their composition these can only originate from the Triassic sandstones, and never could have preserved in a very humid climate. The pebbles have been supplied from the NW, which leads to the conclusion that somewhere amidst the Palaeozoic rocks of the Cantabrian Mountains, but at a small distance from the place of deposition Trias was exposed, and this is now absent from that part of the mountains. If the Triassic sandstone had formed pebbles at a greater distance, these would already have disintegrated during transport.

Mesozoic limestone pebbles are only found near the disconformity with the underlying deposits of the Cuevas facies. Palaeozoic limestones are very rare. So at this time the Mesozoic limestone belt must already have been reduced to a small area, and the Palaeozoic became largely exposed. The many quartzite pebbles must have been supplied partly by the Devonian and Silurian quartzites exposed W of the valley of the river Carrión, and still more by the Carboniferous Curavacas conglomerate. These conglomerates must have had an even greater extension at that time, considering the enormous masses of quartzites deposited in the red beds even far eastward. The strong erosion in the quartzitic rocks and in the Curavacas conglomerate, which has to be presumed, may have been caused by the Styrian orogenetic phase. The alternation of conglomeratic beds with finer grained layers may possibly be a consequence of vegetation, which grew up, and caused the deposits to be much finer. The great extension of the coarse conglomeratic layers within the red beds may be explained as a deposit by braiding rivers, which became overcharged on leaving the mountain area.

The relief in the mountain area at the time of deposition of the sediments presenting the Vega de Riacos facies could have been fairly strong, considering the conglomeratic and coarse sandy character of this facies.

The Vindobonian and Pontian sediments. — The further Tertiary basin sedimentation, as represented by the deposits in Carrión de los Condes, Relea, Zorita and Páramos facies, will be treated as a whole. Sedimentation must have been more or less continuous in the N of the investigated area, without a change of deposit, and in the S with variations in lithology. The absence of coarse gravelly layers means that coarse material, if it was formed at that time, was left in the source area, or that only fine-grained material was supplied.

The climate in the basin must have undergone a change, whereas, during the deposition of the red beds in Vega de Riacos facies, it was still warm and humid, it now became more arid. The lime crusts and gypseous deposits are evidence that evaporation became greater. This change must have been gradual, as can be concluded from the sediments of the Vindobonian and Pontian. At first the yellow sediments in the Vindobonian Carrión de los Condes facies were deposited all over the basin. Later, in the N, evaporating groundwater formed a lime crust during temporary interruptions in sedimentation, whereas in the S the salinity of the water became so great that gypsum could precipitate.

The Pontian Páramos-limestones on top of the gypsum-bearing marls in the S of the investigated area, and the red and yellow clayey deposits in the Relea facies, which do not contain crusts, and the marly sediments in the Zorita facies, demonstrate another change of the climate, becoming more humid now, or at least with less evaporation.

The faunas found in the various deposits (see chapter III) confirm the palaeoclimates, as deduced from sedimentological data. The mammals of the Vindobonian sediments in Carrión de los Condes facies belong to species which lived in a warm climate in the presence of water. The same can be concluded from the mammals and the molluscs of the Pontian.

The intercalated period as it appears from the lime crusts in the N, and the gypsum in the S, points to a restricted drainage, and an increased evaporation. This resulted in the S in a penesaline environment, which seems unfavourable for animal life. In the mountain area the climate was more humid at that time. There was enough water for a sediment to be transported, and the water could not only reach the basin centre, but also pass this arid region over a long distance.

Meanwhile the relief in the Cordillera Cantabrica must have become lower. The lower levels in the sediments presenting the Carrión de los Condes facies which are more sandy than the upper levels in the same facies, may be an indication that bevelling in the source area steadily went on. Although fine sediments, as is known in tropical humid climates, can also be deposited when the relief in the source area is stronger, here it is evident that the relief of the Cantabrian Mountains must have been lower during the sedimentation of the deposits having the Carrión de los Condes facies than during that in the Vega de Riacos facies. This is also in accordance with Solé Sabarís' opinion (chapter IX) on the development of the Meseta and its surrounding mountains.

Pliocene and Quaternary

Pliocene and Early-Pleistocene development. — During the Rhodanian orogenetic phase the Meseta block, and therefore the Duero basin, was uplifted and tilted. Moreover, the surrounding mountain zone rose up relative to the basin. The Meseta now became a non-depositional area, which it remained until the Villafranchian. During the Pliocene an extensive erosion surface must have developed, which along the mountain foot had the character of a pediment. When accepting Mensching's supposition (1958), such relief forms should develop mainly in a tropical savannah-climate. But gradually this climate changed, becoming more arid, in which climate pediments can be preserved. The raña gravels are indicative of a more or less arid climate at the time of their deposition, and the shape of the sand grains shows that possibly it was a time with considerable wind action.

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

The Pleistocene river terraces. — Whereas in the early Quaternary the relief of the basin was rather flat, alternation of cold and temperate climates resulted in the formation of river terraces at different levels. According to various authors slight epirogenetic movements also took place during the whole of the Pleistocene, and possibly until now. The rivers which came from the mountains during the first glacial phases, flowed through a slightly undulating plain, possibly reworking the raña gravels. The highest terrace (T1-level) was formed rather early, its level being situated only 15—20 m below that of the raña. Later repeated erosion and accumulation gave rise to the other terraces and the present river valleys.

The roundness of the pebbles of the T1- and T2-terraces point to a shaping in a humid, but still rather warm, climate. They are certainly not reworked periglacial pebbles (Tricart, written communication). The same conclusions may be drawn from the terrace remainder found near the Astudillo gate at 55 m above the present valley bottom of the Rio Pisuerga. As we may accept that there have been more than four main glacial phases during the Pleistocene (van der Vlerk 1957), this T3-level may also be explained as being due to a cold phase. But whether this level has had only a very limited extension, or whether it was almost fully eroded during a later erosion period, cannot be said. The latter explanation seems the more probable. Remainders could only be preserved, when immediately after the beginning of the new erosion period the river changed its course. This could have been the case with the remnants in the Astudillo gate.

The T4- and T5-terraces show a certain periglacial influence in the roundness of their pebbles. This is in accordance with the opinions of those investigators who accept only two real glaciations for Spain in the mountain areas. These glacials must have been the last and the penultimate.

During the whole of the Quaternary the Cordillera Cantabrica has had a high relief. This caused the transport of great pebbles and cobbles by the rivers. At the present as well the rivers carry such pebbles when, in spring and winter, their water level is high.

It is striking that the terrace gravels contain 96—100 % of quartzites and quartz. The enormous masses of quartzites, which form these gravels, have been eroded from the Curavacas conglomerate in the mountain area, and from the raña of Guardo in the basin. Nossin (1959), who studied the source area of the pebbles in the Cordillera Cantabrica, found no indications that great masses of pebbles had already accumulated during the Villafranchian in these mountains and were thus ready for transportation. Indeed, most of the erosion must have taken place in the Curavacas conglomerate itself during the glacial phases, which was exerted first in a humid climate, and during the last cold periods in a glacial and periglacial climate.

Recent climate and sedimentation. — At present the climate in the Duero basin is a Bsa-climate in the sense of Köppen. In the Cordillera Cantabrica it is more humid, the southern flank being a transitional zone. In winter the mountains have a thick cover of snow. In spring therefore the rivers carry a great quantity of water, even 20 times as much as in summer. During these seasons the erosive power is great, causing a transport of pebbles and much finer material. This material is chiefly derived from the adjacent terraces and from the Tertiary yellow and red clayey deposits, in which many gullies were, and still are, formed. Sedimentation at present only occurs at some places on the river valley bottoms, and at the end of gullies.

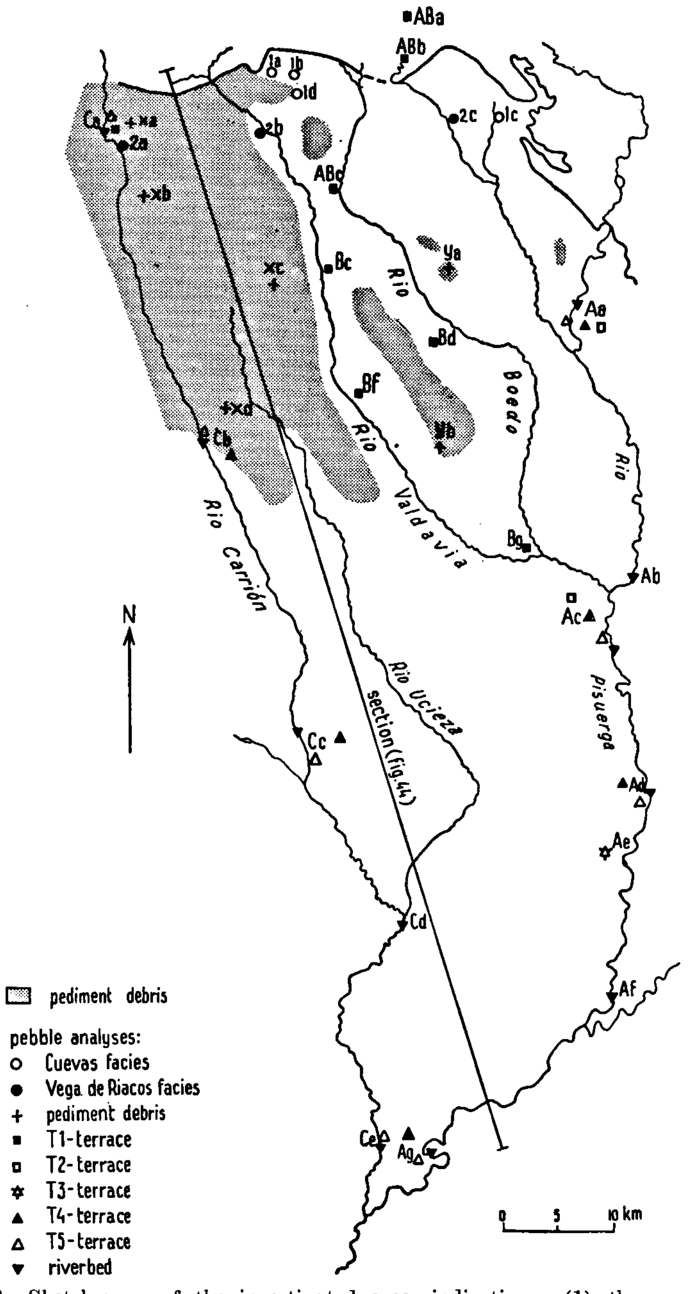

Fig. 48. Sketch map of the investigated area, indicating: (1) the sampling localites of the analyzed pebbles, (2) the extension of the raña and pediment debris, (3) the section line of fig. 44.

PLATE I

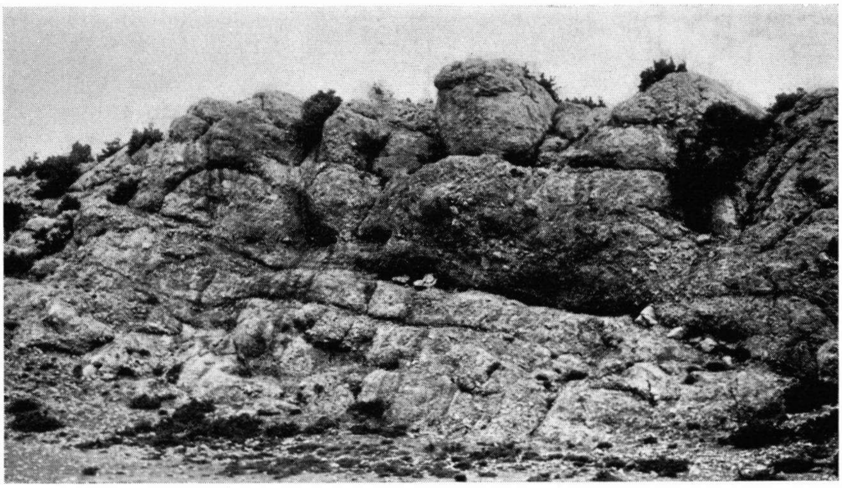

Photo I. Nearly horizontal limestone conglomerates. Cuevas facies, near Barrio de Sta. Maria. (Height of outcrop about 20 m.)

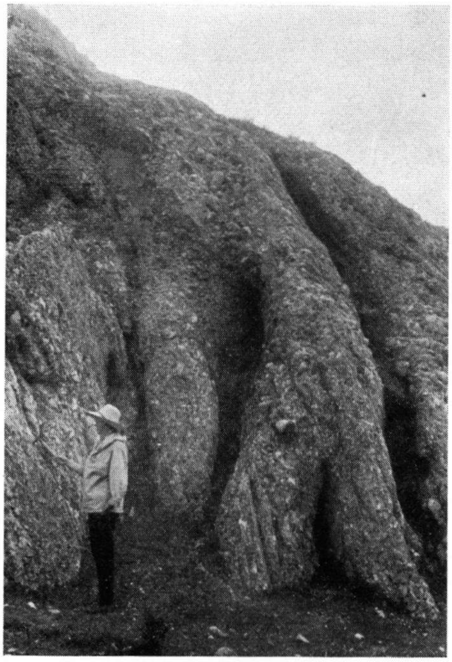

Photo II. Limestone conglomerates in overturned position. Cuevas facies, Rio de las Cuevas.

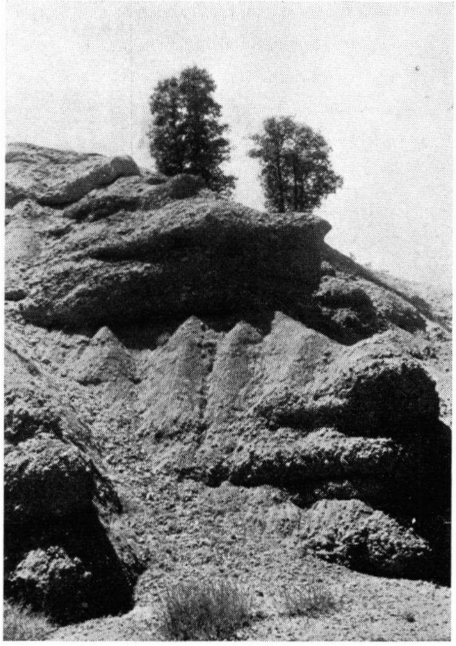

Photo III. Red beds, alternation of quartzite conglomerates and sandy layers. Vega de Riacos facies, near Vega de Riacos on the river Valdavia.

PLATE II

Photo IV. Gully erosion forming a badland topography. Revilla de Collazos on the river Boedo.

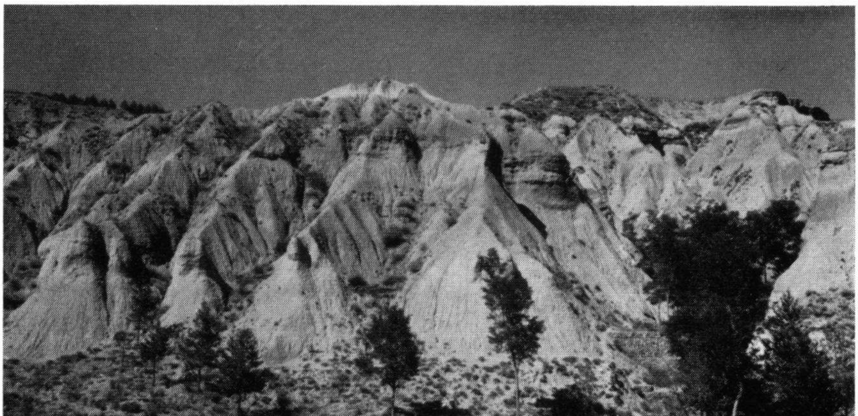

Photo V. Red and yellow sands and clays. Sediments in Relea facies overlying those in Carrión de los Condes facies, near Saldaña.

PLATE III

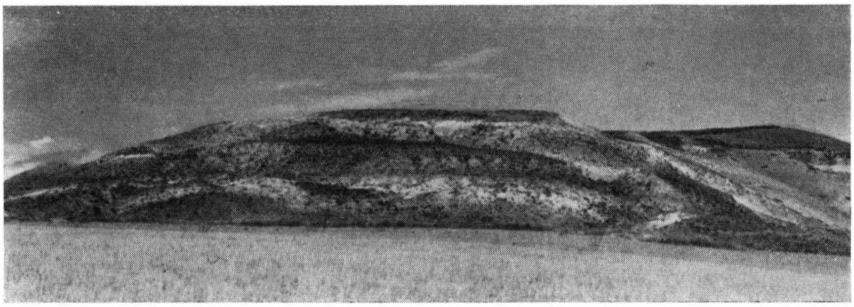

Photo VI. Red sandy layers and white marly layers. Zorita facies, profile of Zorita del Páramo.

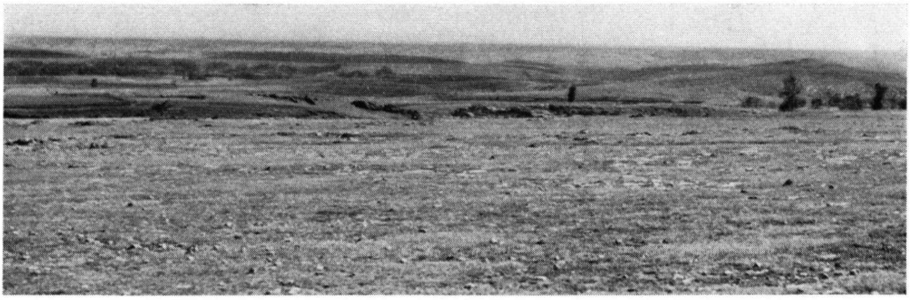

Photo VII. Meseta level from Villanueva de Castrejón. (Photo by J. J. Nossin.)

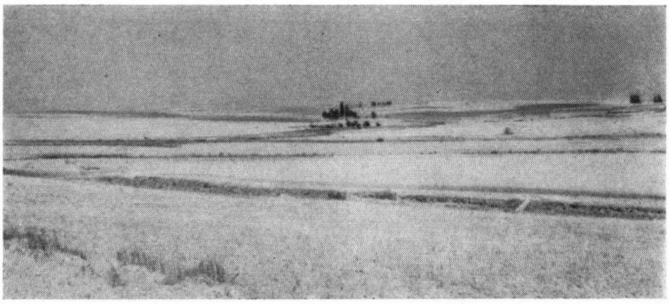

Photo VIII. Castilian landscape near Arconada. Yellow sandy clays in Carrión de los Condes facies, campiña level.

Photo IX. Raña of Guardo, seen towards the Cordillera Cantabrica.

PLATE IV

Gypseous marls and limestones. Páramos facies.

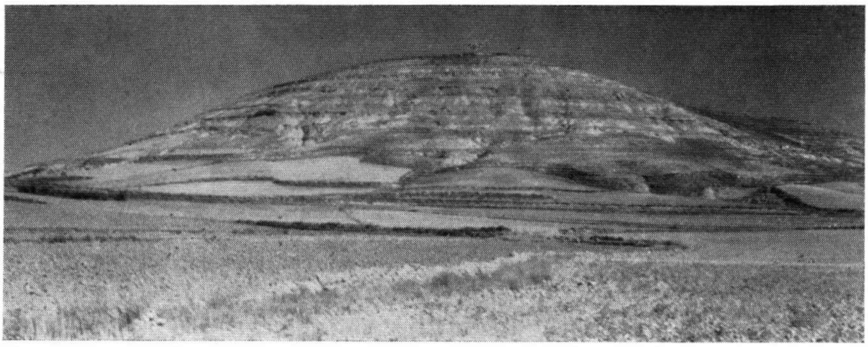

Photo X. Páramo Samonto near Astudillo.

Photo XI. Páramo Taragudillo near Amusco.

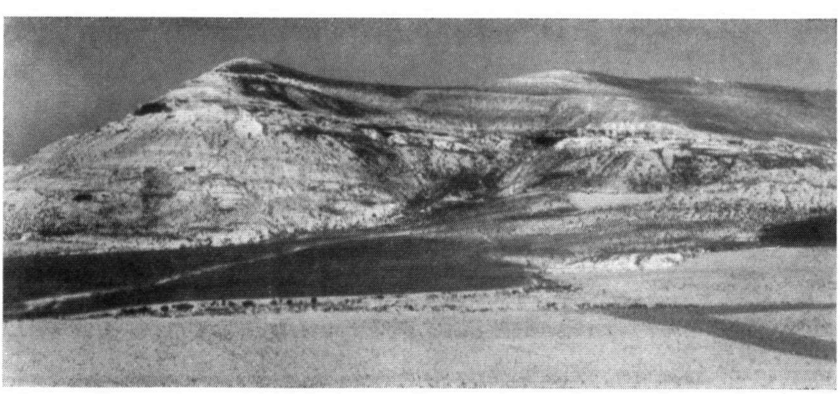

Photo XII. Páramo de la Miranda, north of Palencia.

SUMMARY

Sediments in the foreland of a mountain chain are sometimes suited to reconstitute the conditions in these mountains at the time of deposition of the sediments. The present study gives the results of a sedimentological investigation of the Tertiary and Quaternary deposits in a part of the Duero basin, situated south of the Cordillera Cantabrica, which supplied the sediments. The aim was to determine both the conditions in the source area, and the environments in the area of deposition.

The investigated area is situated in the province of Palencia, between the rivers Pisuerga and Carrión. The area being a part of the so-called Meseta, has a simple relief. Two levels at different heights can be distinguished. The higher level, páramo, is strikingly flat, the lower, campiña, is more undulating.

The Tertiary basin sediments are of various types, and can have six different facies.

Along the mountain foot the sediments are chiefly conglomerates with some sandstones, united into the Cuevas facies. The pebbles consist of limestones derived from the Cretaceous limestones, which in the E occupy extensive areas but in the W are only exposed in a narrow strip along the southern border of the mountain chain. At that time they must have formed the southern flank of the Cantabrian Mountains. Pebble roundness and flatness indicate for the greater part a deposition as river fans in a warm and rather dry climate. These conglomerates have been brought into an overturned position in the W of the investigated area, and were strongly tilted in the E. This tectonic deformation is thought by several authors to have occurred during the Savian orogenic phase. The younger beds, having the Cuevas facies, are nearly horizontal, and were deposited during and after this folding as appears from the presence of sandstone pebbles derived from the sandstone layers within the folded conglomerates.

South of the limestone conglomerate belt a wide zone with red beds occurs. These sediments, consisting of an alternation of quartzite conglomerates and sandy layers, represent the Vega de Riacos facies. The change of deposit from a limestone conglomerate into a quartzite conglomerate may be due to changes in the supply area, the Mesozoic limestones having been eroded and having become covered with soils, and the Palaeozoic quartzites and conglomerates becoming largely exposed. A typical feature is the absence in all basin sediments of pebbles derived from the Carboniferous limestone, the so-called Brezo-limestone, which at present froms a great part of the southern flank of the Cantabrian Mountains. The sediments presenting the Vega de Riacos facies were deposited in a warm and humid monsoon climate, as appears from (1) the red colour, (2) the shape of the quartz sand grains, and (3) the clay mineral associations.

The remainder of the investigated area is characterized in the N by yellow sandy and clayey deposits, covered by similar, but yellow and red, sandy and clayey deposits, and in the S by yellow clayey deposits overlain by white and grey gypseous marls, alternating with limestones.

The underling yellow sandy and clayey sediments, typical for the Carrión

de los Condes facies, are dated as Vindobonian on account of the fossils found near Palencia and Saldaña. The upper yellow and red, sandy and clayey layers found in the N, having the Relea facies, have a Pontian age, based on fossils found near Saldaña and Relea. In the E of the investigated area this Relea facies shows a local divergent aspect, called Zorita facies, characterized by an alternation of red, sandy deposits and white, marly deposits. The gypseous marls and the limestones in the S, which show the Páramos facies, overlying the yellow clayey sediments in Carrión de los Condes facies, have a cover of a very hard, bluish limestone, the Páramos-limestone, which provided some freshwater molluscs indicating also a Pontian age.

The sediments in the four last-named facies represent chiefly deposits of rivers and shallow temporary lakes (*lagunas*). A rather regular sedimentation went on from Vindobonian into Pontian times, meanwhile influenced by changes of climate in the basin. After the warm and humid climate in which the red beds were deposited, the climate became more arid, with an increased evaporation.

First the yellow sediments in Carrión de los Condes facies were deposited, in the N being still sandy, in the S becoming more clayey. They are clearly deposits of rivers which did not supply very coarse material, but some deposition in temporary lakes must also have occurred.

At the end of the Vindobonian evaporation became stronger, as can be concluded from the lime crusts found in the upper layers in the area of the Carrión de los Condes facies, and more to the S, in the area of the Páramos facies, from the deposition of gypsum bearing marls, when the drainage was more or less restricted.

This climate persisted during the first part of the Pontian as can be concluded from lime crusts occurring in the lower beds in Relea facies, the depositional environment, that is rivers and lagunas, remaining the same.

Later in the Pontian the humidity of the climate increased, as appears from the increasing number of red layers in this Relea facies. In the S this increasing humidity caused the precipitation of gypsum to cease, and at this time the Páramos-limestones were formed. The Zorita facies, which laterally replaces the Relea facies, is chiefly determined by a supply from a different source area, namely the Mesozoic calcareous rocks exposed a few kilometres N of the deposits in Zorita facies.

The heavy mineral associations (chapter VIII, part 1) are monotonous, practically consisting of resistant minerals. They seem to indicate a supply from NW to SE. Also the pebble supply followed this direction, as may be concluded from their size distribution within the red beds having the Vega de Riacos facies. This NW—SE direction was the main drainage direction in Pre-Rhodanian times.

The clay minerals in the sediments presenting the various facies allow to draw some conclusions on the climates at the times of deposition. For instance, the rather righ percentage of kaolinite in the sediments in the Cuevas and Vega de Riacos facies, may indicate a warm and rather humid climate during and after deposition. But later alterations also influenced the clay mineral associations, causing a preponderance of illite (see chapter VIII, part 3).

After the deposition of the Páramos-limestones the Duero basin became a non-depositional area. During the Rhodanian orogenic phase the bordering mountains were uplifted, and the basin was tilted towards the W. This caused a switch of the drainage pattern which before was directed towards the Mediterranean, and now became directed towards the Atlantic Ocean. During the whole of the Pliocene strong bevelling occurred, through which the páramo-level in the basin and pediments at the foot of the mountain chains were formed.

Next, a warm and dry climate characterized by sheetfloods must have prevailed all over the Meseta, causing the deposition of the angular quartzitic raña pebbles, so well exposed in the investigated area on the raña of Guardo. These rañas are presumed to be of Villafranchian age.

Soon the influence of Quaternary changes of climate became evident. Certainly the younger river terraces, found at five various levels, are due to these Pleistocene climatic changes. Pebble analyses could confirm the opinion of various authors who admit only two real glaciations in the Spanish mountains, namely the last and the penultimate. Indeed, the two lower terraces contain pebbles which may have been formed in a periglacial climate, whereas the deposits of the three upper terraces only contain evidences of a humid, temperate climate.

The sedimentological data on which the conclusions on the depositional environments, as given above, are based can be found in the following chapters: (a) grain size distribution (chapter V), (b) pebble analyses (chapter VI), (c) morphometrical sand analysis (chapter VII), (d) mineralogy of the sands (chapter VIII, parts 1 and 2), (e) clay minerals (chapter VIII, part 3).

The development of the drainage pattern (see chapter IX) was reconstituted with the help of a number of captures, which can be observed in the field. In this way a gradual adjustment of the drainage to the present direction can be demonstrated. In the investigated area this adjustment occurred rather late during the Quaternary. At that time also the campiña-level was formed.

Finally, in the last chapter (X), an attempt is made to establish the palaeoclimates, and the relief in the source area, though there remain many uncertainties.

The Cordillera Cantabrica, being a mountain area, must always have had a more humid climate than the basin. Even during the Upper-Vindobonian and Lower-Pontian, while the basin was arid, the climate in the mountains must have been more humid. This appears from the clastic sediments supplied into the basin (Relea facies). Though the drainage was restricted, it will not have been totally interrupted, because only calcite and gypsum were deposited in the basin centre, and no halite.

There will have been a certain relief in the source area during the whole time. The sediments give no indications for a fully developed peneplain. During the whole of Vindobonian and Pontian times clastic sediments have been supplied by the Cantabrian Mountains.

RESUMO

Sedimentoj troviĝantaj en baseno limiganta montaron estas kelkfoje uzeblaj por la rekonstruo de diversaj cirkonstancoj, kiel ekzemple reliefo kaj klimato en tiu montaro dum la surteriĝo de tiuj sedimentoj. Tiu ĉi tezo prezentas la rezultojn de sedimentologia esploro pri la Terciaraj kaj Kvaternaraj tertavoloj en parto de la baseno de la rivero Duero en Hispanujo, situanta sude de la Cordillera Cantabrica (Kantabria Montaro), de kie la sedimentoj devenas. La celo de la esploro estis la ekzamenado de la cirkonstancoj en la montaro, kaj de tiuj en la regiono de surteriĝo.

La esplorita regiono troviĝas en la provinco Palencia, inter la riveroj Carrión kaj Pisuerga. Estante parto de la tiel nomata Meseta, ĝi havas nur simplan reliefon. Oni povas distingi du nivelojn je malsama alteco. La supra nivelo, nomata *páramo,* estas tre ebena, la malsupra nivelo, nomata *campiña,* estas pli ondanta.

La Terciaraj basenaj sedimentoj montras diversajn tipojn, kaj povas esti grupataj en ses facioj.

Laŭlonge de la montara piedo la sedimentoj estas grandparte konglomeratoj kaj kelkaj sabloŝtonoj, grupigitaj en la facio de la Cuevas. La rulŝtonoj de la konglomeratoj estas kalkŝtonaj, devenintaj de la Kretaceaj kalkŝtonoj, kiuj en la oriento formas la tutan montaron, kaj en la okcidento estas videblaj nur en mallarĝa zono laŭlonge de la suda deklivo de la montoj. Dum tiu tempo ili formis la tutan sudan flankon de la montaro. Rondeco kaj plateco de rulŝtonoj indikas ĉefe sedimenton de riveraj rubodeltoj en varma kaj sufiĉe seka klimato. Tiuj ĉi konglomeratoj en la okcidenta parto de la esplorita regiono renversiĝis, kaj en la orienta parto forte kliniĝis. La tektonika deformiĝo okazis dum la Savia orogena periodo, laŭ diversaj aŭtoroj. La pli novaj konglomerataj tavoloj kuŝas preskaŭ horizontale, kaj sedimentiĝis dum kaj post la faldiĝo. Tion pruvas la sabloŝtonaj rulŝtonoj, devenintaj de la sabloŝtonoj en la pli malnovaj konglomeratoj.

Sude de la zono kun kalkŝtonaj konglomeratoj troviĝas zono kun ruĝaj sedimentoj. Tiuj konsistas alterne el kvarcitaj konglomeratoj kaj el sabloj, grupigitaj en la facio de Vega de Riacos. La abruptan ŝanĝiĝon de sedimenta tipo verŝajne kaŭzis ŝanĝiĝoj en la montaro, nome erozio de la Mezozoaj kalkŝtonoj kaj ilia malapero sub grundo, kaj la apero sur granda surfaco de la Paleozoaj kvarcitoj kaj konglomeratoj. La sedimentoj de la facio de Vega de Riacos formiĝis en varma kaj humida (malseka, kun multa pluvo), musona klimato, pro (1) la ruĝa koloro, (2) la formo de la sableroj de kvarco, kaj (3) la argilaj mineraloj.

La ceteran parton de la esplorita regiono karakterizas en la nordo flavaj, sablecaj kaj argilecaj sedimentoj sub flavaj kaj ruĝaj, sablecaj kaj argilecaj sedimentoj, kaj en la sudo flavaj, argilecaj sedimentoj sub blankaj kaj grizaj marnoj kun gipso kaj kalkŝtonoj.

La malsupraj, flavaj sedimentoj, grupigitaj en la facio de Carrión de los Condes, devenas de la Vindobonio, laŭ la fosilioj trovitaj en kelkaj tavoloj.

La supraj, flavaj kaj ruĝaj sedimentoj de la nordo, en la facio de Relea, havas Pontian aĝon, ankaŭ pro la fosilioj. En la orienta parto de la esplorita regiono tiu ĉi facio de Relea montras loke deviantan formon, nomatan facio de Zorita, kun alterne ruĝaj, sablecaj sedimentoj kaj ruĝaj ĝis blankaj marnoj. La marnoj kun gipso kaj la kalkŝtonoj en la sudo, grupigitaj en la facio de los Páramos, kuŝas sur la flavaj, argilecaj sedimentoj de la facio de Carrión de los Condes. Ilin kovras tre malmola, blueca kalkŝtono, la Páramos-kalkŝtono, kiu enhavas diversajn, dolĉakvajn konkojn el la Pontio.

La sedimentoj de la kvar, ĵus menciitaj facioj estas ĉefe surterigaĵoj de riveroj kaj de malprofundaj, nedaŭraj lagetoj *(lagunas)*. Sedimentiĝado sen grava interrompo okazis de la Vindobonio ĝis la fino de la Pontio, kelkfoje influita de klimataj ŝanĝiĝoj en la baseno de la Duero. Post la varma kaj humida klimato, dum kiu la ruĝaj tavoloj de la facio de Vega de Riacos sedimentiĝis, la klimato estiĝis pli arida (seka, kiel en dezerto) kun pli granda forvaporiĝo.

Unue la flavaj sedimentoj de la facio de Carrión de los Condes surteriĝis, en la nordo ankoraŭ sabloriĉaj, en la sudo pli argiloriĉaj. Estas klare, ke ili estas sedimentoj de riveroj, kiuj ne alportis tre granderan materialon, sed ankaŭ kelkfoje sedimentiĝado okazis en nedaŭraj lagetoj.

Je la fino de la Vindobonio la forvaporiĝo pligrandiĝis, kion oni povas konkludi el la kalkaj krustoj, troviĝantaj en la supraj tavoloj de la regiono de la facio de Carrión de los Condes, kaj pli sude, en la regiono de la facio de los Páramos, el la formiĝo de la marnoj kun gipso, ankaŭ pro pli malpli limigita defluado de la akvo.

La arida klimato daŭris dum la unua parto de la Pontio, kio estas konkludebla el kalkaj krustoj en la malsupraj tavoloj de la facio de Relea. Sed la sedimentiĝa medio, nome riveroj kaj *lagunas*, restis senŝanĝa.

Pli poste en la Pontio la humideco de la klimato denove pligrandiĝis, kio vidiĝas el la pli granda nombro de ruĝaj tavoloj en la facio de Relea. En la sudo la pli granda humideco ĉesigis la precipitiĝon de gipso. Dum tiu ĉi tempo formiĝis la Páramos-kalkŝtono. La facio de Zorita, kiu ĉeflanke anstataŭas la facion de Relea, formiĝis ĉefe per alportado el aliaj rokoj en la montaro, nome el la Mezozoaj kalkŝtonoj videblaj kelkajn kilometrojn norde de la facio de Zorita.

La grupiĝoj de pezaj mineraloj (ĉap. VIII, parto 1) estas samspecaj, kaj konsistas preskaŭ nur el rezistaj mineraloj. Ili indikas transportiĝon de nordokcidento al sudoriento. Ankaŭ la alportado de rulŝtonoj okazis laŭ tiu direkto, kio estas konkludebla el la divido de iliaj mezuroj en la ruĝaj sedimentoj de la facio de Vega de Riacos. Ĉi tiu nordokcidenta-sudorienta direkto estis la ĉefa deflua direkto en Antaŭ-Rodaniaj tempoj.

La argilaj mineraloj en la sedimentoj de la diversaj facioj ebligas kelkajn konkludojn pri la klimato dum la tempo de sedimentiĝado. Ekzemple, la sufiĉe alta procentaĵo de kaolinito en la sedimentoj en la facioj de la Cuevas kaj de Vega de Riacos indikas varman kaj humidan klimaton dum kaj post la sedimentiĝado. Sed postaj ŝanĝiĝoj ankaŭ influis la grupiĝojn de la argilaj mineraloj, kaj kaŭzis la dominadon de ilito.

Post la sedimentiĝado de la Páramos-kalkŝtonoj la baseno de la Duero fariĝis regiono de erozio. Dum la Rodania orogena periodo la ĉirkaŭaj montaroj leviĝis, kaj la baseno kliniĝis okcidenten. Tio renversis la defluon, kiu antaŭe direktiĝis al la Mediteraneo, kaj poste al la Atlantiko. Dum la tuta Plioceno okazis forto ebeniĝo, kiu formis la *páramo*-nivelon en la baseno, kaj la glacizon laŭlonge de la montaraj piedoj.

Poste, varma kaj seka klimato, karakterizata de surfaca defluo de akvo, regis almenaŭ en la Meseta-regiono. Ĝi kaŭzis sedimentiĝadon de angulecaj kvarcitaj ŝtonoj, tiel bele videblaj en la esplorita regiono sur la *raña* de Guardo. Tiuj *rañas* formiĝis en la Vilafrankio, laŭ diversaj aŭtoroj.

Baldaŭ la sekvoj de Kvaternaraj klimataj ŝanĝiĝoj evidentiĝis. La terasoj de la riveroj, situantaj en kvin diversaj niveloj, estas atribuataj al tiuj klimataj ŝanĝiĝoj. La analizoj de la rulŝtonoj konfirmas la opinion de tiuj aŭtoroj, kiuj akceptas la ekziston de nur du veraj glaciepokoj en la hispanaj montaroj, nome la lasta kaj la antaŭlasta. Nur la du malsupraj terasoj enhavas rulŝtonojn, kiuj eble formiĝis dum periglacia (en la proksimeco de glacio) klimato. La tri supraj terasoj nur indikas humidan, eĉ iomete varman klimaton.

La sedimentologiaj faktoj, sur kiuj la konkludoj pri la sedimentiĝaj cirkonstancoj en la Kenozoo, menciitaj supre, estas bazitaj, troviĝas en la venontaj ĉapitroj: (1) la granulometrio (ĉap. V), (2) la analizo de la rulŝtonoj (ĉap. VI), (3) la morfometria analizo de sablo (ĉap. VII), (4) la mineralogiaj analizoj de sablo (ĉap. VIII, partoj 1 kaj 2), (5) la argilaj mineraloj (ĉap. VIII, parto 3).

La evoluado de la fludirektoj de la riveroj (vidu ĉap. IX) estis rekonstruata helpe de kelkaj ŝanĝiĝoj de tiuj direktoj, videblaj en la tereno. Tiamaniere montriĝas la adaptiĝo de la ĝenerala deflua direkto al la hodiaŭa. En la esplorita regiono tiu ĉi adaptiĝo okazis nur malfrue, dum la Kvaternaro. En tiu ĉi tempo ankaŭ la *campiña*-nivelo formiĝis.

Fine, en ĉapitro X, ni klopodis rekonstrui la praklimatojn kaj la reliefon en la montaro, malgraŭ multaj necertaĵoj.

La Kantabria Montaro ĉiam havis pli humidan klimaton ol la baseno. Eĉ dum la Supra-Vindobonio kaj Malsupra-Pontio, kiam la baseno havis aridan klimaton, ekzistis en la montaro humida klimato. Ĉi tio evidentiĝas el la gruzaj sedimentoj, alportitaj en la basenon (facio de Relea). Kvankam la defluo estis limigita, ĝi ne tute ĉesis, ĉar nur kalcito kaj gipso estis precipitataj en la centro de la baseno, kaj ne halito.

La reliefo en la montaro ĉiam estis sufiĉe alta, preskaŭ neniam ebena. La sedimentoj ne havigas indikojn por ebligi konkludojn pri ebena reliefo. Dum la tutaj Vindobonio kaj Pontio gruzaj sedimentoj estis alportataj de la Kantabria Montaro.

Pro manko de geologia terminaro diversaj terminoj uzataj estas arbitraj.

RESUMEN

Los sedimentos en el antepaís de una cordillera se prestan a veces muy bien a la reconstitución de las condiciones en la cordillera en los tiempos de la deposición de estos sedimentos. El presente estudio da los resultados de una investigación sedimentológica sobre los depósitos terciarios y cuaternarios en una parte de la cuenca del Duero, al S de la Cordillera Cantábrica que suministró los sedimentos. El objeto fué determinar tanto las condiciones en la región original como las circunstancias de la región sedimentaria.

La región estudiada está situada en la provincia de Palencia entre los ríos Carrión y Pisuerga. Siendo parte de la Meseta, la región tiene un relieve sencillo. Dos niveles se distinguen a alturas diferentes. El nivel superior, el páramo, es notablemente plano, el nivel inferior, la campiña, es más ondulado.

Los sedimentos terciarios de la cuenca son de tipos distintos, agrupados en seis facies.

Junto al pie de la cordillera los sedimentos son, en su mayoría, conglomerados con unas areniscas, agrupados en la facies de las Cuevas. Los cantos se componen de calizas, derivados de las calizas cretáceas que ocupan amplios terrenos en el E, pero en el W sólo una faja estrecha que deslinda el sur de la Cordillera Cantábrica. El aplanimiento y desgaste de los cantos indican por la mayor parte un depósito de cono de deyección fluvial en un clima cálido y bastante seco. Estos conglomerados se han volcados en el W de la región estudiada, y se han inclinado considerablemente en el E. Según varios geólogos, esta deformación tectónica se ha efectuado en la fase Sávica. Los tramos posteriores, que pertenecen a la facies de las Cuevas, son casi horizontales. Se depositaron durante y después del plegamiento, como se evidencia del hecho de que los cantos de arenisca fueron derivados de las areniscas que se encuentran entre los conglomerados plegados.

Al S de los conglomerados calcáreos se encuentra una zona ancha con capas rojas (red beds). Estos sedimentos, que se componen alternativamente de conglomerados de cuarcita, y de arenas, presentan la facies de Vega de Riacos. El cambio del depósito de conglomerado calcáreo en conglomerado cuarcítico puede deberse a cambios ocurridos en las montañas, erosionándose las calizas mesozoicas y cubriéndose de suelos, y aflorándose las cuarcitas y los conglomerados paleozoicos. Un fenómeno muy típico es la ausencia, en todos los sedimentos de la cuenca, de cantos derivados de la caliza carbonífera, la llamada caliza de montaña, que en la actualidad ocupa gran parte de la ladera sur de la Cordillera Cantábrica. Los sedimentos que tienen la facies de Vega de Riacos se depositaron en un clima cálido y húmedo de monzón, como se evidencia de (1) el color rojo, (2) la forma de los granos de cuarzo y (3) los conjuntos de los minerales de arcilla.

El resto de la región estudiada lo caracterizan en el N depósitos arenosos y arcillosos de color amarillo cubiertos de depósitos arenosos y arcillosos de color amarillo o rojo, y en el S depósitos arcillosos amarillos cubiertos de margas yesíferas de color blanco o gris, y de calizas.

Los sedimentos arenosos y arcillosos inferiores de color amarillo, agru-

pados en la facies de Carrión de los Condes, pertenecen al Vindoboniense, en razón de los fósiles hallados cerca de Palencia y de Saldaña. Los sedimentos arenosos y arcillosos superiores de color amarillo o rojo en el N, que presentan la facies de Relea, pertenecen al Pontiense, también en razón de fósiles hallados cerca de Saldaña y de Relea. En el E de la región estudiada, esta facies de Relea enseña un aspecto localmente distinto, llamado la facies de Zorita, en que alternan sedimentos arenosos rojos y sedimentos margosos de color blanco o rojo. Las margas yesíferas y las calizas en el S, que juntas tienen la facies de los Páramos y que cubren los sedimentos arcillosos amarillos en la facies de Carrión de los Condes, están cubiertas de caliza compacta, muchas veces de color azulado, la llamada caliza de los páramos, que contiene algunos moluscos de agua dulce, pertenecientes también al Pontiense.

Los sedimentos en las últimos cuatro facies son principalmente depósitos de ríos y de lagunas (zonas endorreicas, como la presente Laguna de La Nava). Una sedimentación bastante regular continuó realizándose desde el Vindoboniense hasta el Pontiense, influyendo en ella a la vez cambios de clima en la cuenca. Después del clima cálido y húmedo, en que las capas rojas se sedimentaron, el clima se volvió más árido y con mayor evaporación.

Primero se depositaron los sedimentos amarillos que presentan la facies de Carrión de los Condes, siendo aún arenosos en el N, y volviéndose más arcillosos en el S. Son evidentes depósitos de ríos que no arrastraban material muy grueso, pero ocurrió también alguna deposición en lagunas.

A fines del Vindoboniense, la evaporación aumentó, como se evidencia de las costras de cal halladas en los tramos superiores de la región de la facies de Carrión de los Condes, y, más al S en la región de la facies de los Páramos, de la deposición de margas yesíferas, reduciéndose el desagüe en major o menor grado.

Este clima perduró durante la primera parte del Pontiense, como se evidencia de las costras de cal que se encuentran en los tramos inferiores en la facies de Relea, quedando las mismas las circunstancias de sedimentación, es decir mediante ríos y lagunas.

Más tarde en el Pontiense, el clima se hizo más húmedo, como se evidencia del número creciente de capas rojas en la facies de Relea. En el S, la humedad creciente hizo parar la precipitación de yeso; durante esta época, se formó la caliza de los páramos. La facies de Zorita, que substituye lateralmente la facies de Relea, la determina principalmente la aportación procedente de una región original distinta, a saber las calizas mesozoicas que afloran pocos kilómetros más al N.

El conjunto de los minerales pesados (cap. VIII, 1) es sencillo, se compone casi sólo de minerales resistentes. Parecen indicar un transporte del NW al SE. También el transporte de los cantos siguió la misma dirección, como se evidencia de la distribución de sus tamaños en las capas rojas que tienen la facies de Vega de Riacos. Esta dirección del NW al SE fué la dirección principal del desagüe en los tiempos pre-rodánicos.

Los minerales de arcilla en los sedimentos en las diversas facies permiten sacar algunas conclusiones sobre el clima en el tiempo de sedimentación. Por ejemplo, el porcentaje bastante elevado de caolinita en los sedimentos agrupados en las facies de las Cuevas y de Vega de Riacos puede indicar un clima cálido y húmedo durante y después de la deposición. Pero cambios posteriores también influyeron en los conjuntos de minerales de arcilla, produciendo una preponderancia de ilita (cap. VIII, 3).

Después de la deposición de las calizas de los páramos, la cuenca del Duero quedó un área de erosión. Durante la fase orogénica rodánica, la orla montañosa se levantó y la cuenca se inclinó hacia el W, causando un cambio completo del desagüe, que antes se dirigía hacia el Mediterráneo y después hacia el Atlántico. Durante el Plioceno entero, un aplanimiento fuerte ocurrió, formando el nivel del páramo en la cuenca, y los pedimentos al pie de los montes.

Luego, un clima cálido y seco, caracterizado por "sheetfloods", dominó en toda la Meseta, causando le deposición de los cantos angulosos de cuarcita de raña, tan bien expuestos en la región estudiada en la raña de Guardo. Estas rañas se atribuyen al Vilafranchiano.

Pronto, la influencia de los cambios de clima en el Cuaternario se hizo sensible. Sin duda, las terrazas fluviales más recientes, situadas en cinco niveles distintos, deben su origen a estos cambios de clima. Análisis de los cantos confirmaron la opinión de varios autores que suponen la existencia de sólo dos períodos glaciarios en las montañas de España, a saber el último y el penúltimo. En efecto, las dos terrazas inferiores tienen cantos que pueden haberse originado en un clima periglaciario, presentando los depósitos de las tres terrazas superiores sólo indicaciones de un clima húmedo y templado.

Los datos sedimentológicos, en que están basadas las conclusiones sobre las circunstancias de deposición y que se dan arriba, pueden encontrarse en los capítulos siguientes: (a) granulometría (cap. V), (b) análisis de los cantos (cap. VI), (c) morfometría de los granos de arena (cap. VII), (d) mineralogía de las arenas (cap. VIII, 1 y 2), (e) los minerales de arcilla (cap. VIII, 3).

El desarrollo de las direcciones de drenaje (cap. IX) se reconstituyó con la ayuda de unas captaciones, que pueden observarse sobre el terreno. De esta manera puede ser demostrado un cambio gradual de la dirección de desagüe hacia la dirección presente. En la región estudiada, este cambio ocurrió en una época bastante avanzada del Cuaternario, época en la cual se desarrolló también el nivel de la campiña.

Finalmente, en el último capítulo (X) hemos intentado hacer la reconstitución de los paleoclimas y del relieve de la cordillera, aunque quedan existiendo muchas incertitudes.

La Cordillera Cantábrica, siendo una región montañosa, ha tenido siempre un clima más húmedo que la cuenca. Aún durante el Vindoboniense superior y el Pontiense inferior, cuando la cuenca era árida, el clima en los montes quedaba más húmedo. Esto se evidencia de los sedimentos clásticos depositados en la cuenca (facies de Relea). Aunque limitado, el desagüe nunca se suspendió totalmente, puesto que sólo se precipitaron calcita y yeso en el centro de la cuenca, y no halita.

La cordillera tendría siempre cierto relieve. Los sedimentos no indican una penillanura bien desarrollada. Durante los enteros períodos Vindoboniense y Pontiense, sedimentos clásticos fueron suministrados desde la Cordillera Cantábrica.

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