ORIGIN OF THE TERTIARY RED BEDS IN THE NORTHERN PART OF THE DUERO BASIN (SPAIN).

I. GRAIN SIZE, ROUNDNESS, AND SPHERICITY*).

BY

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ABSTRACT

Red sediments of Tertiary age crop out alongside the southern border of the Cantabrian Mountains in the northern part of the Duero basin. They consist mainly of conglomerates with quartzite pebbles, sandstones, and sandy, loamy, and marly deposits, all with a deep red colour.

Detailed analyses were made on grain size composition, on pebble roundness, and on sand grain roundness and sphericity. The results are presented in triangle-diagrams for nomenclature, cumulative curves of size frequency distributions, graphs showing changes of sediment properties with transport distance, and in a facies map. The following conclusions can be drawn: (1) the source area of the sediments was a mountain chain with outcropping Paleozoic and Mesozoic deposits and their weathering products; (2) the transport of the debris occurred by rivers, which flowed in a south-easterly direction; (3) the deposition took place in the mountain foreland, the coarse sediments being deposited nearer to the mountain area than the finer ones; (4) the transport length was fairly short; (5) the conglomerates exposed in the source area provided rounded pebbles to the gravelly sediments deposited in the basins (6) the rivers left the mountain area at the same sites as the present ones.

Finally the description of two type locality sections gives an impression of the red bed lithology.

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INTRODUCTION

In the Duero basin, alongside the southern border of the Cantabrian Mountains (Cordillera Cantabrica), a belt of red sediments of Tertiary age is exposed (fig. 1). These deposits have never been studied minutely, and thus almost no reference to previous literature can be made. The aim of this study is to give a sedimentological interpretation of these beds in some more detail, and over a wider area, than we did in our previous work (Mabesoone 1959). The only comparable study is by Riba (1955) on similar deposits in the western part of the Ebro basin.

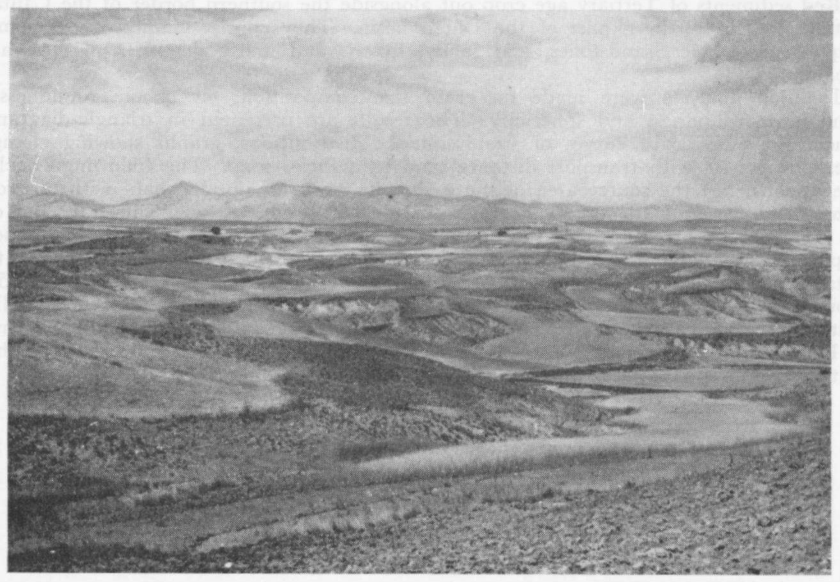

Fig. 1. Zone with outcropping Tertiary red beds; in the background, the Cantabrian Mountains.

In our present article the grain size, roundness, and sphericity of the red beds will be described; in a later report the mineralogy and the genesis of these will be discussed.

LOCATION AND GEOLOGICAL SETTING

The area studied occupies about 1800 square kilometres in the Duero basin alongside the southern border of the Cantabrian Mountains, at some distance from it. It extends from La Robla in the valley of the river Bernesga in the province of León in the W, to Villadiego in the valley of the river Brulles in the province of Burgos in the E. It follows the southern border of the mountains, and curves with it towards the SE between the valleys of the present rivers Boedo and Odra (fig. 2). The region occurs on the following sheets of the

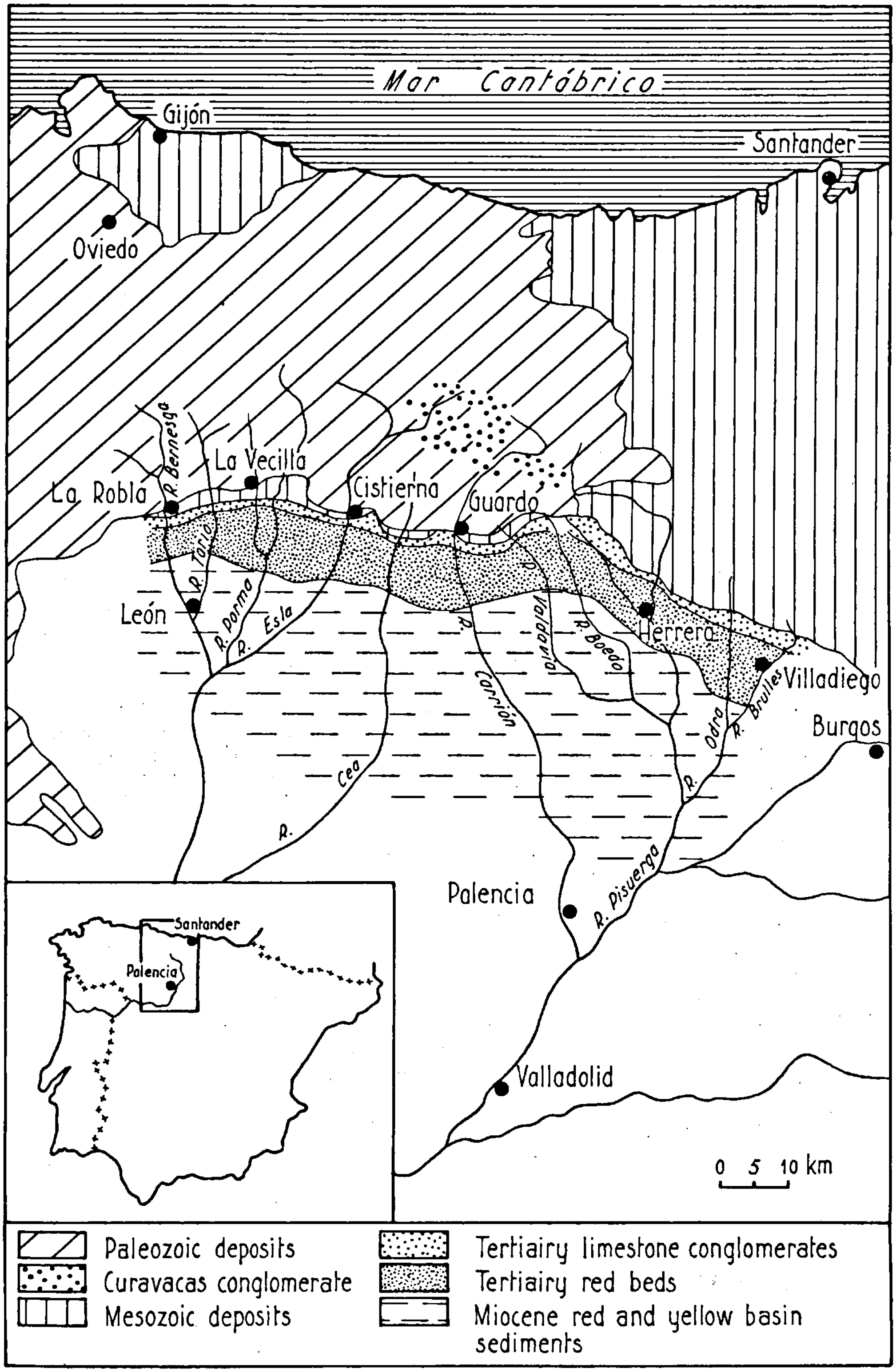

Fig. 2. Location and regional geology.

topographical maps of the scale 1: 50000, published by the "Instituto Geográfico y Catastral": 104 (Boñar), 129 (La Robla), 130 (Vegas del Condado), 131 (Cistierna), 132 (Castrejón de la Peña), 133 (Prádanos de Ojeda), 163 (Villamizar), 164 (Saldaña), 165 (Herrera de Pisuerga), 166 (Villadiego), and 199 (Sasamón).

The main geological features important to this study, which are also shown on the index map, are: (1) Paleozoic sediments of the mountain area, found only W of the Sierra de Peña Labra and the Rubagón valley, consisting mainly of quartzites, limestones, conglomerates, and shales (De Sitter 1961 a, b); (2) Mesozoic sediments of the same mountain area, occupying the whole of the region E of the Rubagón valley, and also a narrow strip alongside the southern border of the Paleozoic belt; they consist of conglomerates, sandstones, marls, and limestones (Ciry 1939); (3) Tertiary conglomerates, which consist exclusively of pebbles of Cretaceous limestones, and occupy the whole zone between the Mesozoic deposits and the red sediments studied. South of the region with red deposits younger red and yellow sands and clays are found, which extend towards the centre of the Duero basin, of no importance for the present study. The only published sheets of the geological map of Spain, of the scale 1: 50000, on which the red beds are figured, are numbers 133 (Prádanos de Ojeda) and 163 (Villamizar); in the accompanying memoirs, however, no sedimentological data has been published.

With regard to the age of the Tertiary limestone conglomerates and the red beds no reliable data can be obtained, because fossils have never been found in these deposits. For reasons explained earlier (Mabesoone 1959) we attribute an Oligocene to Lower-Miocene age to the limestone conglomerates, and a Burdigalian to Lower-Vindobonian age to the red sediments. But all datings remain uncertain, so they will not be further mentioned.

The red beds were deposited disconformably upon the limestone conglomerates with which they show a small mixing zone. They are in the S conformably overlain by the red and yellow sands and clays typical of the more central part of the Duero basin. In almost the whole area they are covered by a thin layer of late Tertiary and Quaternary gravels.

SAMPLING AND ANALYSIS

The outcrops of the red beds occur chiefly in the river valleys. At the steep slopes complete profiles can be studied and measured (figs 13 and 14). They often suffered a deep gully erosion, sometimes forming a badland topography (fig. 14).

From such outcrops, which often do not show a great lateral extent, every bed has been sampled. Material finer than 2 cm has been studied in the laboratory, coarser material in the field, both with the usual sedimentological methods. A total of 250 fresh samples, taken from the layers exposed in a number of representative outcrops, were examined in this way.

The majority of the data given for the Esla region has been taken from an internal report by Wolf (1959).

LITHOLOGY

The sediments studied are conglomerates, sands, loams, and more rarely marls and calcareous sandstones. They all have a red or reddish-brown colour (5 R val. 4—6 chr. 4—6, 7.5 R val. 4—6 chr. 4—6, 10 R val. 4—7 chr. 2—6, and sometimes 5 YR val. 6—8 chr. 4—6, of the Munsell colour scale). Only once has a greyish-white, reduced, layer been found, just below a thin lignite layer.

The whole belt has been divided into three zones, the first situated near the boundary with the limestone conglomerates, the third near the boundary with the yellow and red basin sediments, the second being the middle zone. In the first zone (I) the sediments are chiefly conglomerates alternating with sandstones and sands. The middle zone (II) has less conglomerates, which are finer too, more sandstones and sands, and also a few layers of loam and sandy marl. The third zone (III) finally contains sands, loams, and marls, lacking all coarse pebble containing deposits.

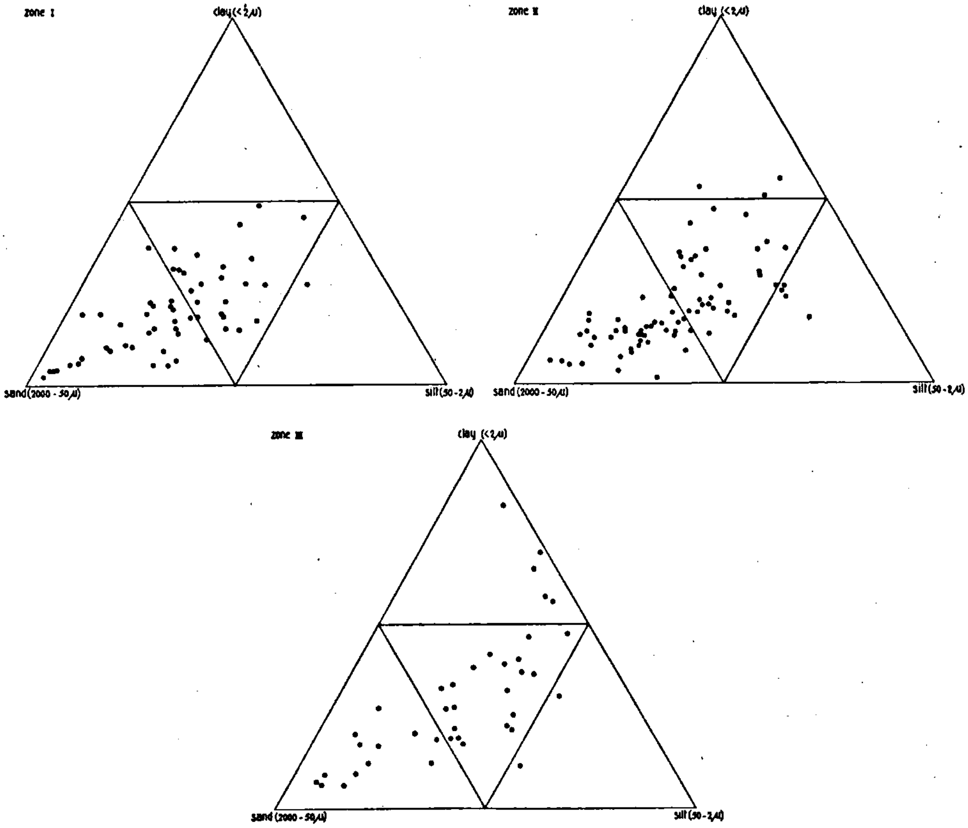

Fig. 3. Sand-silt-clay triangle-diagrams.

Because total grain size and carbonate analyses were available of all sediments, with the exception of the conglomerates, it was easy to assign the proper names to them. For the nomenclature the principles proposed by Füchtbauer (1959) have been used, with the exception that the term "loam" is applied for those sediments having < 50 % of their particles in the three main groups: sand, silt, and clay. When putting the data in triangle-diagrams (fig. 3) it is striking that the sediments containing less than 25 % of carbonate matter, are almost only sands and loams; that is to say that they are relatively coarse. In zone I the majority of the sediments are sands; in zone II the majority also lies in the sand size fraction, but there already occur some clays and silts; finally in zone III loams chiefly are met with. It appears from these three diagrams that pure clays and silts are very rare; the finer deposits still contain a rather high percentage of particles $> 50\,\mu$.

The sediments containing more than 25 % carbonate matter have been presented in triangle-diagrams as given in fig. 4. The majority of the samples are calcareous sandstones and sandy marls. Here again in zones I and II most of the sediments are sandy: calcareous sandstones and sandy marls. Zone III has only a few deposits containing > 25 % of carbonate matter, being in the majority marly sediments, although calcareous sandstones are present too.

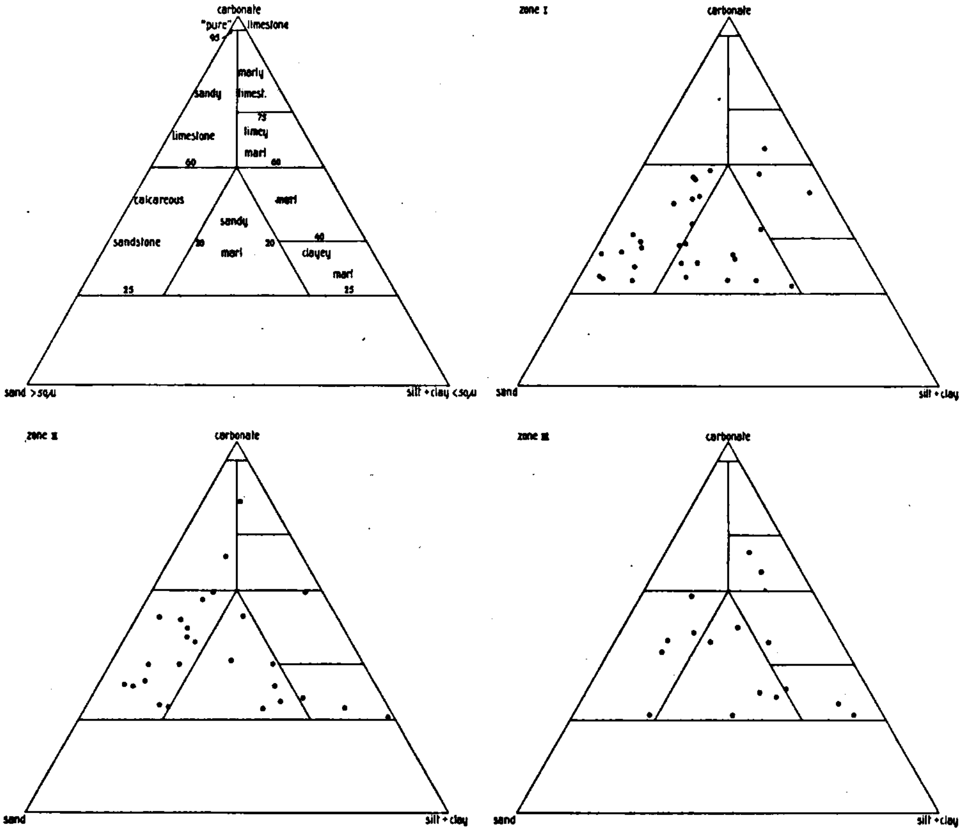

Fig. 4. Carbonate-sand-silt + clay triangle-diagams, and nomenclature

GRAIN SIZE

A grain size analysis of a conglomerate, carried out in the field, is a rather time-consuming process. So we made only a few analyses of some typical layers from zones I and II, by means of the method proposed by Hörner (1944). An advantage in this case was that nearly all pebbles are quartzites, so that only a few specimens had to be weighed in order to obtain a good average specific weight of the pebble fractions. In fig. 5 the average conglomerates of zones I and II are presented in a cumulative frequency curve. Sample I has its dominant size class between 25 and 10 cm, whereas the matrix (> 2 mm) forms 20 % of the total. The sample of zone II is finer, having its modal class between 13 and 2 cm, with only 14 % of matrix.

The finer deposits have been analyzed by means of the combined sieve-

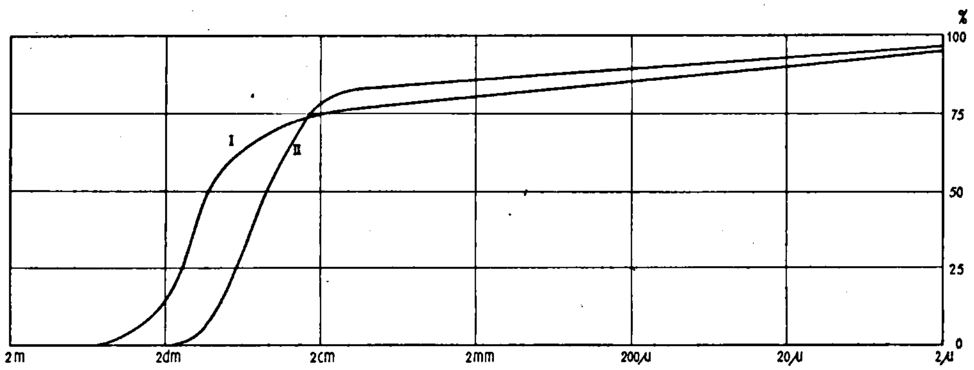

Fig. 5. Size frequency distribution of two conglomerates.

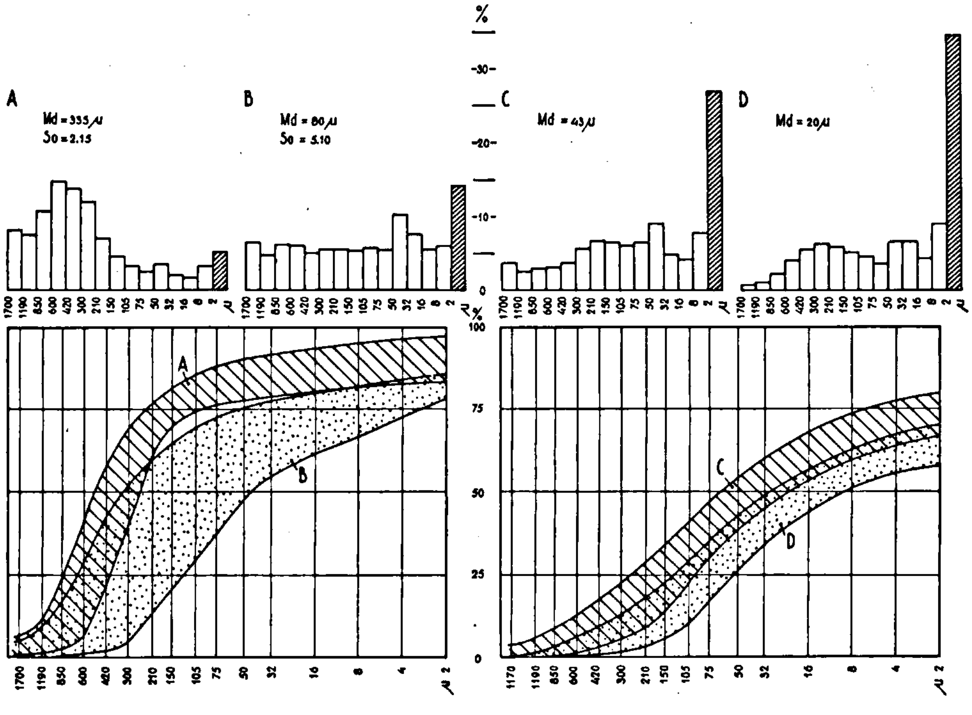

Fig. 6.

A. Size frequency distribution of sands (zone diagrams A and B) with average samples.
B. Size frequency distribution of loams (zone diagrams C and D) with average samples.

pipette method (see Mabesoone 1959, p. 69). For the presentation of their size frequency distributions the division into three geographical zones has not been followed. It was found that the sands of all three zones have their frequency distributions within a narrow zone on the graph, so that they have been grouped into one. In fig. 6 A two main groups of sands are presented in this way, one with 75 % or more in the sand size fraction, and one with 50—75 % of sand, > 10 % of clay, and > 10—20 % of silt. In the same figure a histogram shows the average sample of each group [1]).

The sands of group A are fairly coarse, and they have their median size class for the greater part in the medium sand size grade (420—210 μ). The sands of group B, on the other hand, occupy a wider range; their medians lie in the grades of medium, fine (210—105 μ), and very fine (105—50 μ) sand. For this group it can be remarked that the lower the percentage of particles greater than 50 microns, the finer the sand fraction.

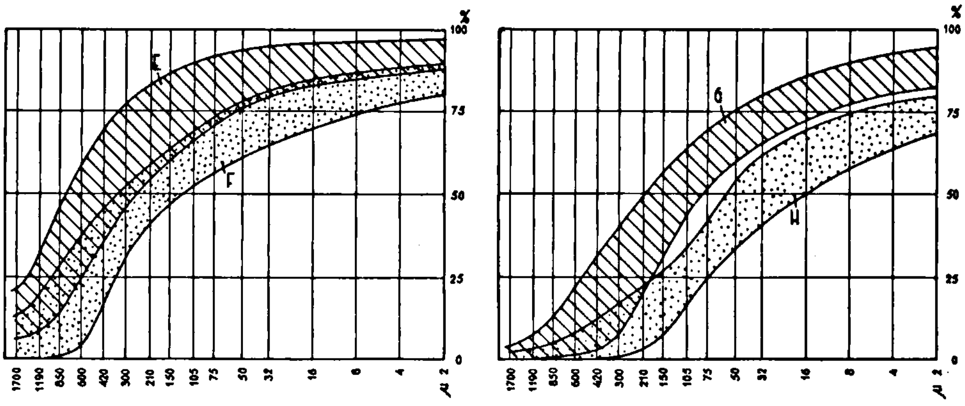

Fig. 7. Size frequency distribution of the non-carbonate fraction of calcareous sandstones (zone diagrams E and F), and sandy marls (zone diagrams G and H).

In fig. 6 B the loam groups C (containing 40—50 % of sand), and D (containing less than 40 % of each group) are presented, with their average samples. The zones enveloping the cumulative curves, are narrower than those of the sands, and lie closer together. The median values of group C lie in the size grades of very fine sand, and of coarse silt (50—16 μ), those of group D in the size grades of coarse, and fine (16—2 μ) silt.

In the same way the results of the grain size analyses of the insoluble residues of the deposits containing more than 25 % carbonate matter are figured. The left part of fig. 7 shows two zone diagrams of size frequency distributions of the calcareous sandstones, that of group E showing those with > 75 % sand, that of group F those with < 75 % sand. The right part presents the two zone diagrams of sandy marls, G having > 50 % sand leaving out of consideration the percentage of carbonates, and H being that of the calcareous loams. The groups E, F, and G, when comparing them with the deposits containing less carbonate, show much congruity with the groups A and B of fig. 6 A, and the

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[1]) Concerning the use of this type of "histogram" we may refer to our previous remark (Mabesoone 1959, p. 70).

same applies to group H, when comparing it with the loam groups C and D of fig. 6 B. That is why this group H has been called that of the calcareous loams. It may thus be concluded that the later infiltration with carbonate matter, and the following cementation, occurred in the same types of sediments as those with less calcareous matter.

Although, when possible, the statistical values Md (median) and So (sorting) have been determined, they do not show any relation to other data. The general tendency is that the higher the Md-values, the better the sorting. But when denominating the sorting values as proposed by Füchtbauer (1959), it becomes obvious that 147 samples are poorly-sorted, only 13 medium-sorted, and 5 well-sorted. Even So-values as great as 11—14 have been found! In table 1 the means of the statistical values of each figured sediment group are given. The results only confirm the conclusions already made from the size frequency distributions.

Table 1. Averages of statistical values of grain size composition

group	Md (median)	So (sorting)	number of samples
A	296 mm	2.45	24
B	95	4.77	46
C	39	6.00	35
D	18.6	—	10
E	335	2.17	20
F	200	5.29	12
G	125	3.27	6
H	33	—	14

ROUNDNESS AND SPHERICITY

For the pebbles of the conglomerates the methods introduced by Cailleux (summary 1956) were used. Only his dissymmetry-index was rejected as being inefficient for our purposes.

The roundness- and flatness-indices are presented in table 2, showing the median index values for each river system, the modal index class, and, for the roundness only, the percentages of pebbles having an index < 100 and > 500. For comparison we added the values of the Carboniferous Curavacas conglomerate

Table 2. Roundness and flatness of quartzitic pebbles from the conglomerate beds

	roundness				flatness	
present drainage area	median index value	modal class	100	500	median index value	modal class
Bernesga	342	300—400	6 %	10 %	1.88	1.5—2.0
Torio	398	400—500	2	20	1.91	1.5—2.0
Porma	356	300—400	6	12	1.83	1.5—2.0
Esla	446	300—400	—	28	2.00	1.5—2.0
Cea	458	500—600	—	44	1.78	1.5—2.0
Carrión	323	300—400	6	12	1.98	1.5—2.0
Valdavia	318	300—400	—	8	1.94	1.5—2.0
Burejo	332	300—400	2	16	2.03	1.5—2.0
Pisuerga	286	200—300	4	8	1.77	1.5—2.0
Curavacas congl.	—	300—400	—	10	—	—

given by Nossin (1959), as part of the pebbles are thought to have been derived from this conglomerate. In most cases the dominant class is that with indices between 300 and 400 for roundness, and always between 1.5 and 2.0 for flatness. The majority, therefore, of the median index values for roundness also lies between 300 and 400, and that for flatness between 1.5 and 2.0.

As to the roundness of the sand grains only the fraction 1—$^1/_2$ mm, separated during the treatment for mineralogical analysis, has been measured. Cailleux's methods for measuring roundness proved to be too time-consuming. For that reason the method proposed by Pettijohn (1957, p. 59) has been used, which divides the sand grains into 5 roundness-classes. At the same time the two-dimensional sphericity (projection sphericity) as proposed by Rittenhouse (1943) could be established.

In table 3 the results of each zone, and for each river drainage area are presented, with the average of the total.

Table 3. Roundness and sphericity of quartz sand grains

present drainage area	zone I roundness	 spher.	zone II roundness	 spher.	zone III roundness	 spher.	average roundness	 spher.
Bernesga	0.237	0.780	0.293	0.807	—		0.261	0.791
Torio	—		0.210	0.772	0.217	0.780	0.212	0.776
Porma	0.198	0.770	0.195	0.767	0.210	0.776	0.202	0.772
Esla	0.269	0.788	0.256	0.792	—		0.267	0.789
Cea	0.253	0.784	0.233	0.781	—		0.241	0.782
Carrión	—		0.236	0.783	0.225	0.783	0.232	0.783
Valdavia	0.254	0.786	0.252	0.788	0.241	0.788	0.251	0.788
Boedo	0.231	0.777	0.232	0.783	0.234	0.786	0.232	0.783
Pisuerga	0.266	0.788	0.221	0.778	0.224	0.781	0.240	0.783
Odra	0.268	0.788	0.266	0.796	0.282	0.805	0.270	0.792

In fig. 8 roundness values have been plotted against projection-sphericity values. It is evident that the line for group I is a little steeper than those for groups II and III, but the difference is only small. The line M of the average of the sum lies between them, and shows a normal path. It is striking that, although roundness and sphericity are independent values, they have a relation to each other. In contrast to what has been found in other studies (Pettijohn 1957, p. 60), sphericity values are relatively high if compared with moderate roundness.

Fig. 9 shows roundness plotted against grain size (i. c. median). There is not much relation: the points lie scattered over a great area in the diagram. Neither does the division into zones show any differences.

DISCUSSION

The data obtained by all the analyses previously described, provides sufficient information for conclusions on sedimentation circumstances. Though more complete information on the origin of these red beds can only be obtained by detailed mineralogical study, first conclusions will be given here.

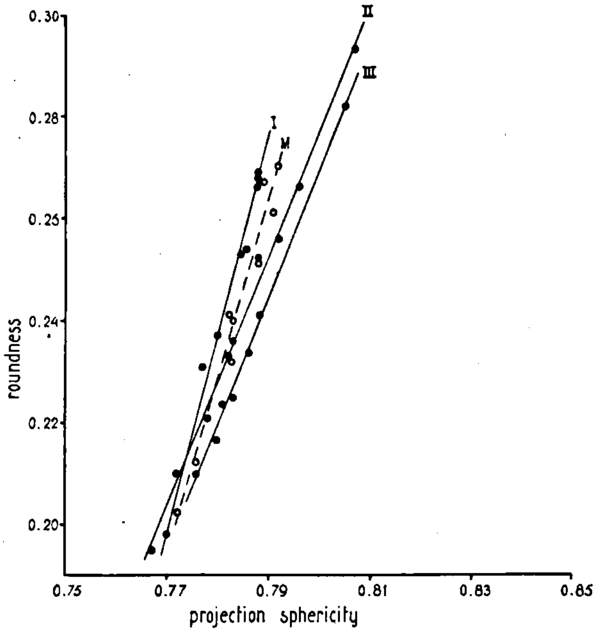

Fig. 8. Roundness values of quartz sand grains plotted against sphericity values.

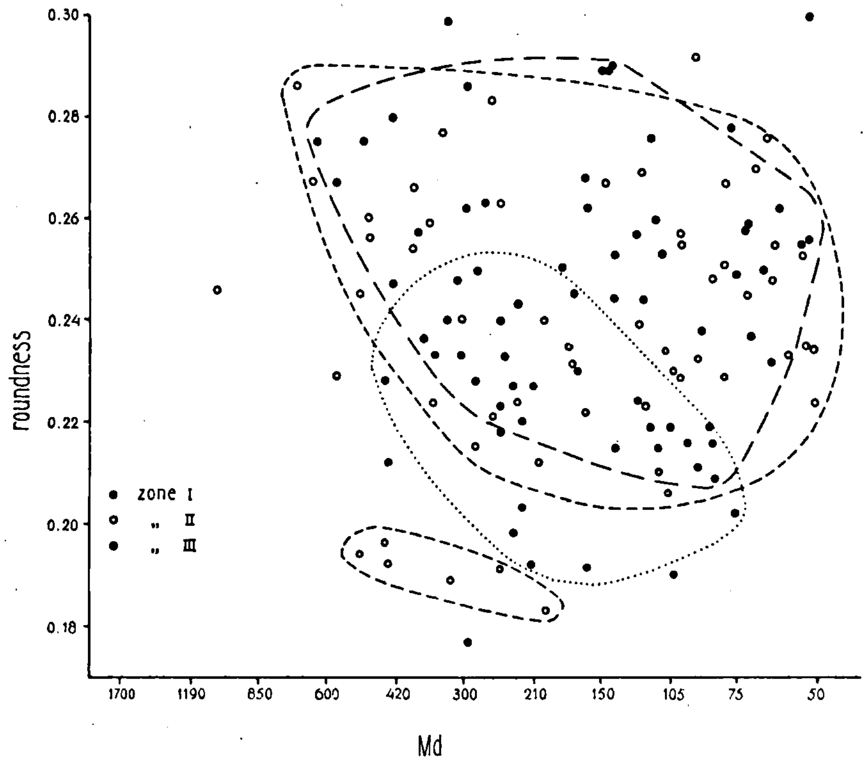

Fig. 9. Relation between roundness of sand grains and median grain size.

Depositional environment

The variety of the sediments, their rapid alternation, and the fact that the beds are rather thin, demonstrate the rapid change in the circumstances of the depositional environment. Such an environment is provided by braiding rivers with varying competency, frequently shifting.

The conglomerates indicate a supply of coarse material from a region either with considerable vertical erosion, or with a conglomeratic belt, the cement of which weathered easily. The region of deposition must have been rather flat, because the sediment beds are almost horizontal, or have a dip of only a few degrees. So the area of deposition must have been a piedmont alluvial plain. The pebbles incline downstream, but not steeply. The sorting is very poor, the size classes ranging between 50 cm and $< 2\,\mu$. The roundness and flatness of the conglomerate pebbles (table 2) point to a shaping in a warm climate by fluviatile action (compare the data provided by Tricart & Schaeffer 1950). The roundness is rather high, higher than commonly occurs in a deposit near a mountain range.

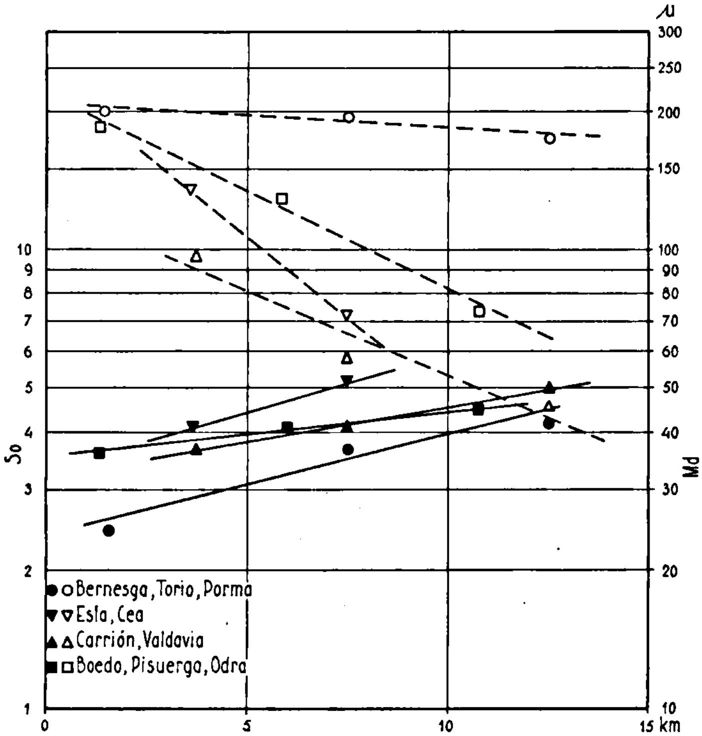

Fig. 10. Median grain size (dashed lines) and sorting (continuous lines) in their relation to distance from the northern boundary of the belt with red beds.

The other sediments also point to a supply by rivers, because of the decrease of the median grain size towards the S and SE, away from the source area, and the poor sorting. In fig. 10 this data is assembled. The decrease of

Md-values in the Esla region and more to the E is rather great, whereas towards the W it is smaller. An increase of So-values towards a still poorer sorting in a south-easterly direction is also evident. This change in sorting is due to the greater clay content of the deposits. We presume that farther from the mountains, where finer grained deposits occur, vegetation could grow more rapidly, thus sieving out the fine clay particles from the passing suspended sediment. This might explain the general tendency that with decreasing Md-value the So-values increase (fig. 11). In general in a fluvial environment with slowly streaming water differences of deposition velocity are less important.

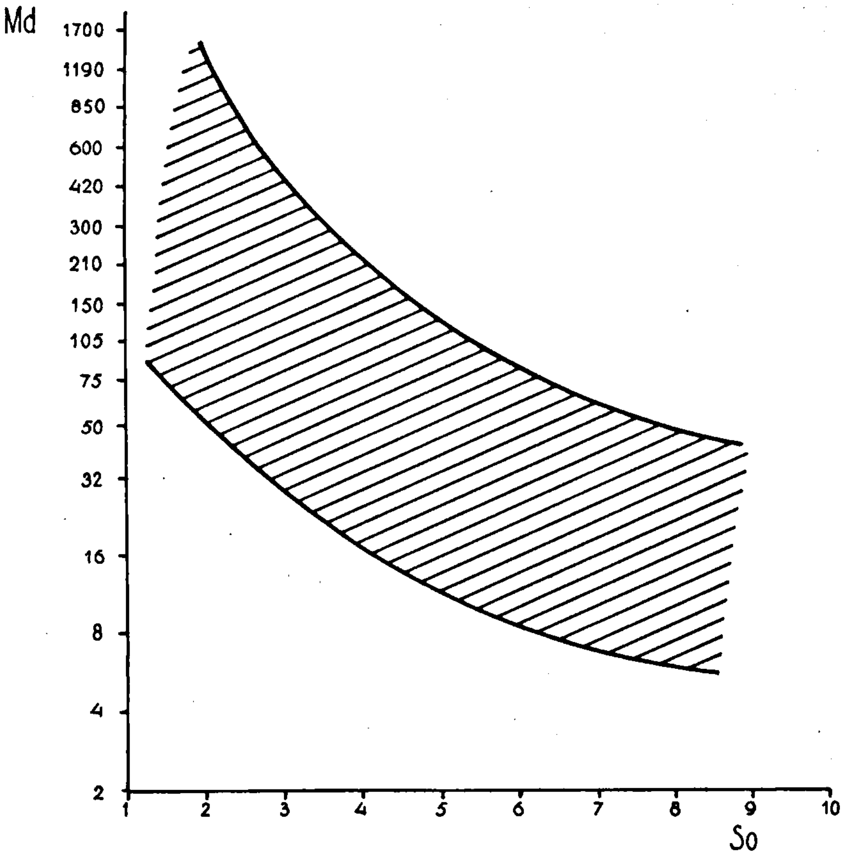

Fig. 11. Relation between median grain size and sorting.

Roundness and sphericity of the quartz sand grains give no effective information. Roundness remains fairly moderate, fluviatile action being unable to wear sand grains rapidly (Kuenen 1959). In some regions it increases towards the SE, in others it decreases (table 3). The same can be said of the sphericity. A relation between median grain size and roundness does not exist (fig. 9).

Provenance

When comparing the roundness analyses of the conglomerate-pebbles with that of the Curavacas conglomerate, a good measure of agreement is striking. This conglomerate produces at present extensive talus slopes consisting of weathered-out quartzitic pebbles, which are eventually taken up by the rivers. This leads to the conclusion that many pebbles in the red beds may have been derived from the conglomerate; their roundness was already so high that no further rounding occurred. However, the Curavacas conglomerate is only found in the mountain region between the rivers Esla and Pisuerga (fig. 2). The quartzite pebbles in the area W of the Esla (at present drained by the rivers Porma, Torio, and Bernesga), and also those in the Esla and Cea regions, must have been derived from other conglomerates, or from freshly weathered quartzites. There are, indeed, conglomerates of Stephanian age in this area (De Sitter 1961 b). Whether fresh quartzites contributed to the supply cannot be said with certainty; if they did, the pebbles have acquired during their transport the same degree of roundness as those from the conglomerates, as the roundness-index graphs do not show polymodal or bimodal distributions. Anyhow, the source area must have had an appreciable relief, with valley slopes from which great quantities of quartzite pebbles (or angular fragments in the case of fresh quartzites) were released.

The carbonate content of the red beds varies with the amount of limestone occurring in the source area (table 4). It is high in the E, where the rivers run through Mesozoic limestones, and in the Esla area, where extensive limestones occur; for the other drainage areas it is below 25 %.

Table 4. Percentage of deposits containing more than 25 % of carbonate matter

NW	Bernesga region	16.7 %
↓	Torio	15.4
	Porma	22.7
	Esla	42.9
	Cea	20.0
	Carrión	—
	Valdavia	19.8
	Boedo	40.6
	Pisuerga	33.4
SE	Odra	42.7

From these analyses it may be concluded that at the time of deposition of the red beds the Cantabrian Mountains existed as a mountain region with considerable vertical erosion, and with a number of important rivers draining this mountain chain towards the S and SE.

Transportation

All data previously given indicates a rapid transportation as is evident from the beds of conglomerates, deposited by braiding rivers, which became overcharged on leaving the mountain area. The Paleozoic sediments of the Cantabrian Mountains supplied a fairly great quantity of clastic particles of all sizes. In the NW-part the decrease of the median grain size in a direction away from the mountain area (fig. 10) is fairly small. This may be due either to a greater competency of the rivers, or to a supply also from the W, because the boundary of the Duero basin curves towards the S only a few kilometres W from the

Bernesga valley. In the SE-part, in the regions of the rivers Pisuerga and Odra, where almost no conglomerates occur, these clastic particles, derived from the Paleozoic, were transported over a greater distance because of the greater width of the Mesozoic belt; the sediments here are therefore much finer.

The transport direction was from NW to SE. This is easily seen from the facies map (fig. 12) discussed below. Although cross-bedding in the sandy sediments and in the conglomerates has not been found, this transport direction can also be reconstructed from the dips of the individual pebbles in so far as they have a high flatness.

Possibly also as a consequence of transport direction is the absence of fairly fine deposits in the W-part of the area studied (namely the drainage areas of the present rivers' Bernesga, Torio, and Porma). Here the drainage direction in zones II and III was more or less W—E, the finer deposits being transported farther, and mixed with those of other rivers as e. g. the Esla and the Carrión.

Textural maturity

The sediments are textural immature in the sense of Folk's definition (1951). The high clay content, the poor sorting, the low to moderate roundness of the quartz sand grains, all point to his stage 1 (immaturity). Only the pebbles of the conglomerates have reached their final roundness-values, thus being mature. But the provenance of these pebbles from a well-rounded conglomerate may not lead to the conclusion that the conglomeratic deposits in the red beds are mature. Also the abundance of gravel components of a large size class (even boulders, > 256 mm) point to immaturity.

FACIES MAPPING

Because the profiles in the river valleys are well exposed over a considerable height, ratios of the various sediment types were easily obtainable. In fig. 12 a facies map has been constructed, showing the relative abundance of the sediments.

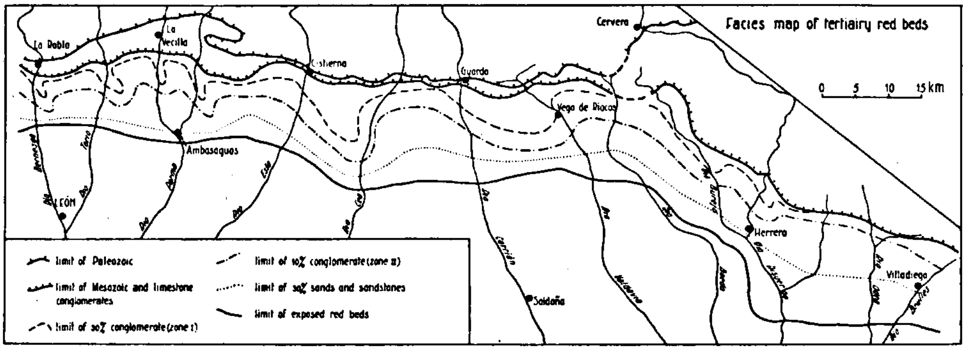

Fig. 12. Facies map of the Tertiary red beds.

The coarser conglomerates (of zone I) all occur in a fairly narrow strip, with tongues from NW to SE at those places where the present rivers enter into the Duero basin. The boundaries between these zone I-conglomerates, the zone II-conglomerates, the sands and sandstones, and the loams and sandy marls, all run more or less parallel. This leads one to the conclusion that, at the time of sedimentation of the red beds, on the same sites as at present, rivers must have existed. Only in the drainage areas of the present Cea, which comes from a basin with Stephanian deposits, and of the present Valdavia, which does not come from the Cantabrian Mountains at all, the coarse sediments must have been supplied by other rivers, namely the Tertiary Esla, and the Tertiary Carrión, respectively. This can easily be seen from fig. 12. So in table 2 a bracket unites the pebble roundness-indices of Esla and Cea, and of Carrión and Valdavia, indicating a common provenance.

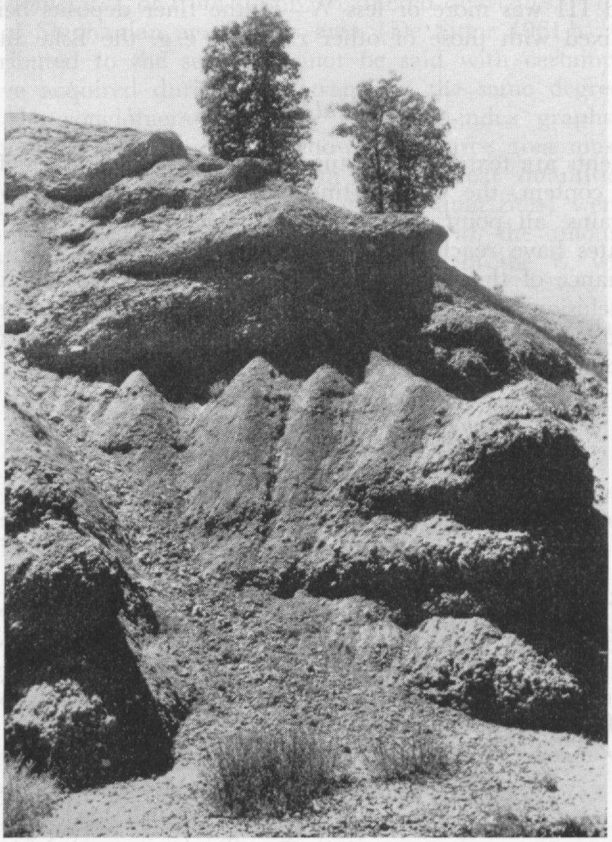

Fig. 13. Outcropping red beds near Vega de Riacos on the river Valdavia.

Striking are the coarse conglomerates of group I found at the site where the present Pisuerga river enters the Duero basin. At the time of the red bed sedimentation the Pisuerga did not flow there, because it ran straight south through the so-called Brezo-gate (Nossin 1959) into the valley at present drained by the small river Boedo (Mabesoone 1959). At that time, therefore, another river must have entered the basin at the place where now the Pisuerga is. Its exact course cannot be reconstructed, but certainly it came from the NW, where the quartzites are exposed in the Paleozoic belt of the Cantabrian Mountains.

Farther in a south-easterly direction, in the present drainage area of the river Odra, conglomerates of group I are absent, only a few conglomerates of group II, and finer ones, are present, indicating a transport over a longer distance in the course of which the coarse fraction was sorted out.

Calcareous pebbles were not supplied to the area of deposition of the red beds, though there may have been some vertical erosion in the Mesozoic limestone belt, as was the case in the Paleozoic core of the Cantabrian Mountains. If limestone pebbles were formed at that time, they either disappeared through solution, or through transport. The important carbonate supply is evident, however, from the varying amounts of carbonate cement (compare table 4).

DESCRIPTION OF TWO TYPE LOCALITIES

Finally two type localities will be described. The first is that of Vega de Riacos (fig. 13) in zone II, the second near Ambasaguas (fig. 14) in zone III.

Near Vega de Riacos, in the present Valdavia valley, though in the supply area of the Tertiary Carrión river, 47 m of red beds are exposed. They consist of conglomerates, typical for zone II, alternating with sands and loams, moderately cemented by carbonate matter. All beds have the same colour, namely 7.5 R 6/5 of the Munsell scale. In fig. 15 all deposits have been termed, and the groups to which they belong according to the zone diagram of size frequency distribution, have also been added. It appears that the sands generally form the lower beds,

Fig. 14. Red beds exposed in an "arroyo" near Ambasaguas at the confluence of the rivers Porma and Curueño.

the loams the upper ones. Furthermore the conglomerates become somewhat finer upward. So during the time of deposition of the red beds, the debris supply from the mountain region must have become finer. It points to a further stage of denudation in the source area, though still with considerable vertical erosion, and great transport capacity of the rivers. All deposits contain 10—20 % of carbonate matter, indicating a sufficient carbonate content of the waters passing through the pores at that time or later. To give an example: from one layer of 2 m three samples were taken, one from the upper part, one from the middle, and one from the lower part. This last sample is somewhat finer than the other two, at least its Md-value is smaller, though still lying in the very fine sand size grade. Sorting is poorer due to the higher clay content. It is possible that this bed during its sedimentation did not differ from the others, but that later some of the clay migrated and accumulated in the lower part.

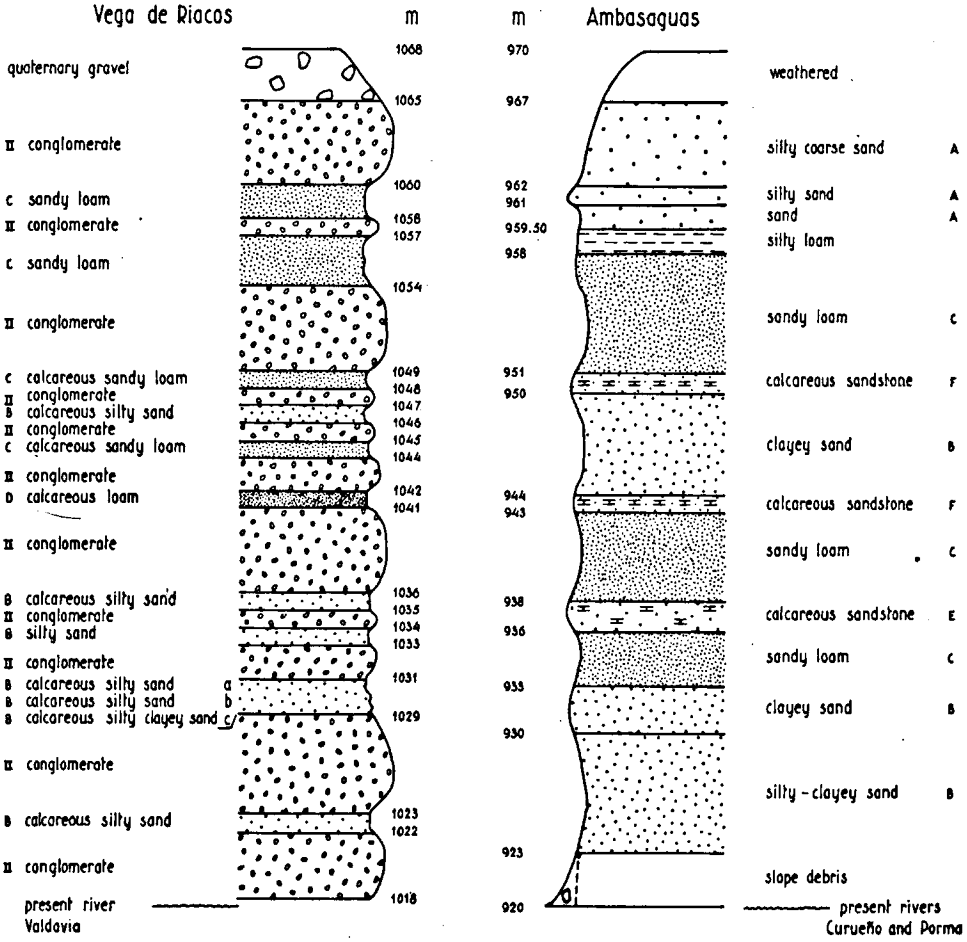

Fig. 15. Sections illustrating typical red bed formation lithologies.

North of Ambasaguas, in an "arroyo" near the confluence of the Porma and Curueño rivers, 50 m of red sediments are exposed. Here sandstones, sands, and loams are found, lacking all coarse deposits, and therefore typical of zone III. Not all the beds have the same colour, the finer deposits being somewhat more intensively coloured. Here, as can be concluded from fig. 15, the sediments do not become finer upward. The outcrop lies in the region W of the present Esla river, which region shows only a small decrease of median grain size in a southeasterly direction (see fig. 10). The absence of carbonate matter in the majority of the deposits is obvious, they are thus less consolidated.

CONCLUSIONS

Much information on the provenance, transport, and depositional environment of the red beds could already be obtained from the grain size, and roundness and sphericity analyses alone. Further information, especially on paleoclimate, has to be obtained from mineralogical and petrographical data, to be discussed later in part II.

These red beds were supplied both by the debris of Paleozoic rocks, and by that of the Mesozoic rocks. They were transported by rivers coming from a mountain region, and deposited in its foreland. These rivers flowed towards the SE, the general drainage direction at that time (Mabesoone 1959, chaps IX and X). These Tertiary rivers must have come out from the mountain area, and entered into the basin region, at nearly the same sites as at present. Farther from the mountain area the deposits become finer with decreasing Md-values.

The transport distance was short, but long enough for the quartzite pebbles to gain their maximum roundness, in so far as they had not yet obtained it before their removal from the mountain area. The short transport was also the cause of the textural immaturity of the sediments, though much of the clay could have been added to the deposits by sieving out through vegetation, which must have been abundant, as appears e. g. from the thin lignite layer found.

SUMMARY

The red sediments exposed in the northern part of the Duero basin have been discussed as to their grain size distribution, roundness, and sphericity.

1. Grain size and lithology point to a supply by rivers, and a fairly short transport from the source area (the Cantabrian Mountains) to the area of deposition. From NW to SE, that is in the transport direction, the sediments become finer, and the sorting poorer.
2. Roundness of the quartzite pebbles from the conglomeratic beds must be the consequence of a shaping by fluviatile action in a warm climate, in so far as they did not already get their shape in the source area.
3. Roundness and sphericity of the quartz sand grains give no reliable information, because of the short transport distance.
4. Textural immaturity is also a consequence of the short transport. The fairly high clay content may, at least partly, be due to vegetation, which sieved out the fine particles.
5. The lithology of the source area is reflected much more in the coarse basin deposits than in the finer ones.

RESUMEN

Las capas rojas ("red beds") que afloran en el norte de la cuenca del Duero, se han tratado de sus granulometría y morfometría de los cantos y granos de cuarzo.

1. La granulometría y la litología indican una sedimentación por ríos y un transporte muy corto, de la región montañosa (la Cordillera Cantabrica) a la región sedimentaria.

2. El desgaste de los cantos de cuarcita se debe a una modelación fluvial de clima cálido, en cuanto eso no es debido a una procedencia de conglomerados ya rondeados.

3. El desgaste y la esfericidad de los granos de cuarzo de la fracción arena no proveen datos seguros por la distancia corta de su transporte.

4. Inmaturidad textural también es una consecuencia del transporte corto. El porcentaje bastante elevado de la fracción arcilla es debido, en parte, a la vegetación que acribó las partículas finas.

5. La litología de la región montañosa se refleja mas en los sedimentos gruesos de la cuenca que en los sedimentos finos.

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