GEOLOGIE EN MIJNBOUW VOLUME 50 (3), p. 399-416 1971

MOLASSE AND CLASTIC-WEDGE SEDIMENTS OF THE SOUTHERN CANTABRIAN MOUNTAINS (NW SPAIN) AS GEOMORPHOLOGICAL AND ENVIRONMENTAL INDICATORS

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ABSTRACT

Post-orogenic sediments supplied by the Cantabrian Mountains during successive stages of uplift, were of the molasse type during the Stephanian and later of the clastic-wedge type. Sedimentological research has provided information on the source area and the environmental and climatic conditions under which these generally coarse-grained sediments were deposited: warm and humid for Upper Carboniferous, warm and relatively arid for Triassic and Tertiary times. The depositional environments were in all cases torrential, alluvial fans grading into flood plains with finer grained sediments.

INTRODUCTION

The Cantabrian Mountains in northwestern Spain have at various times supplied large amounts of coarse clastic material which accumulated in intramontane and foreland basins. This supply went on, although with interruptions, from Upper Carboniferous to Upper Tertiary times. During this long period, however, the character of the sediments varied (fig. 1).

The first deposits laid down after the main Hercynian orogenesis are so similar to the molasse deposits of the Alpine mountain chain that the term molasse has been applied, among others by Virgili and Corrales (1966), Evers (1968), and Reading (1970), to these rocks of Stephanian age. The use of the term molasse in the sense of: detritus worn from elevated ranges during and immediately after the major diastrophism, deposited in the late foredeep, ..." and "... a typical formation common to all large mountain chains ..." has not been limited to either the Alps or to deposits of Tertiary age of that particular type (van Waterschoot van der Gracht, 1931).

From the Permian onward the coarse-grained formations, although still products of terrigenous alluvation from the denuding, rising near-by Cantabrian Mountain chain, took on a different character. For these deposits the use of the term molasse is less appropriate; the deposition of detritus is separated by a long lapse of time from Hercynian events such as the deposition of flysch sediments, folding, and post-orogenic epeirogenesis. They belong to different geological cycles in the sense of Harpum (1960). These sediments with an alluvial-fan character show a less striking similarity to the Alpine molasse deposits, and for these sediment bodies the more neutral term clastic wedge, as introduced by Pettijohn (1957) and later used by King (1959) and Krumbein and Sloss (1963) is preferred. Although the formations described in this paper all represent some particular form of tectonically induced sedimentation, it will be clear that the formations cannot be covered by the same nomenclature. Therefore, the Upper Carboniferous sediments of Stephanian age will be referred to as *molasse* deposits, whereas the deposits of Permian, Triassic, and Tertiary ages will be described under the heading of *clastic-wedge* sediments.

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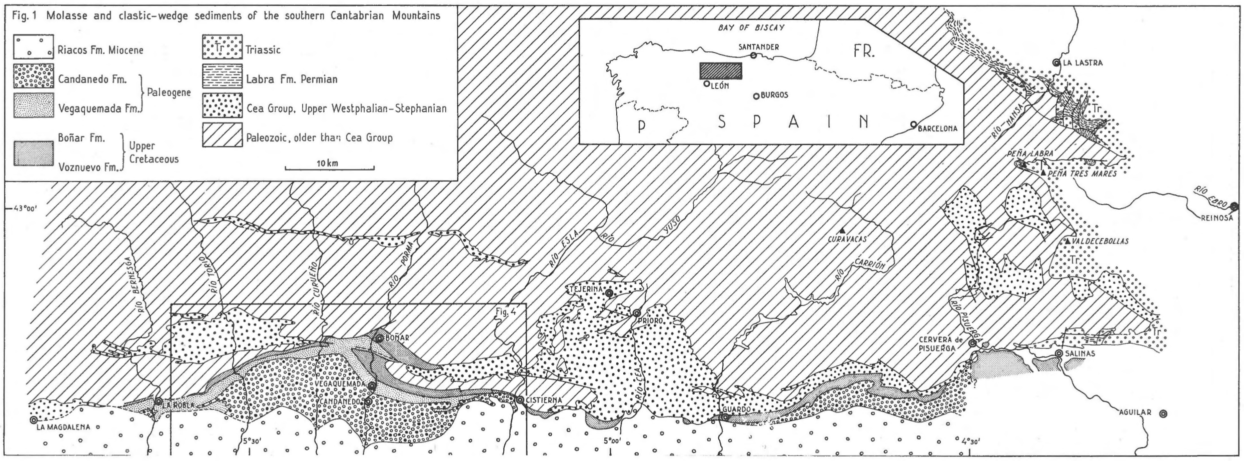

Fig. 1
Molasse and clastic-wedge sediments of the southern Cantabrian Mountains.

Foreland deposits of a mountain chain not only give information on the environmental and climatic conditions of the area of deposition, but can also supply information on the geomorphology, weathering, and exposed rocks of the source area, i.e. the mountain range itself. The principles have been elucidated by such authors as Cadisch (1928), Birot (1955), and Pannekoek (1957). Some conclusions referring to the geomorphology of the source area are also given here.

The present compilation of the sedimentological knowledge concerning these post-orogenetic deposits is based partly on publications by staff members of the Department of Geology of Leiden University and others, and partly on unpublished M.Sc. theses by the author's students in the Sedimentary Geology Section of the same department and on his own field observations.

CARBONIFEROUS MOLASSE SEDIMENTS

Before the main or Asturian orogenic phase, which occurred at the beginning of or during the Westphalian D, a wide variety of rock types (sandstones, shales, pebbly mudstones, limestones, and conglomerates) were deposited, together constituting the Upper Carboniferous Yuso Group. These rocks represent various depositional environments, including turbidite basins, basin slopes, shallow basins, and, possibly, alluvial fans.

After the Asturian orogeny, the sediments of the Cea Group, representing the molasse phase in the history of the Cantabrian Mountains, were deposited during the Westphalian D and the Stephanian, mainly in intramontane basins.

The sediments of the Cea Group in most places unconformably overlie previously folded and eroded strata. Basal rocks of the Cea Group range in age from Upper Westphalian D to Stephanian A-B in the eastern and central parts of the southern Cantabrian Mountains, whereas still younger rocks, of Stephanian B-C, age, form the base farther to the west.

From data published by Helmig (1965), Rupke (1965), Evers (1968) and Boschma & van Staalduinen (1968) and the author's observations, the following picture of the Cea-Group sediments could be established. The Cea-Group sediments, 4,000 to 5,000 m thick, consist of grey, well-cemented, very coarse quartzite conglomerates with well rounded cobbles and boulders of a high degree of sphericity; conglomerates with subangular limestone boulders and pebbles; lenses of coarse to fine-grained micaceous sandstones; greywackes; carbonaceous mudstones; and coal beds. The sediments show rapid and frequent lateral changes in lithology. Marine fossils were found in intercalated shale or sandstone beds, but the marine intercalations never take an important share of the total thickness of the sediments and the Cea Group deposits have in general a continental (torrential, fluviatile, and limnic) character (photo 1). There is, however, an increase of marine intercalations towards the east, resulting in a lateral transition from a continental fluvio-limnic

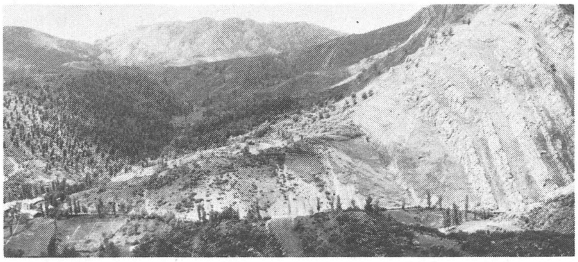

Photo 1
Upper Carboniferous section, north of Tejerina, looking W. Layers of conglomerate in the basal part (right), coal-bearing fining-upward fluvial sequences, near the village in the top (left), and a marine intercalation between.

facies in the west towards a paralic and turbiditic facies in the east.

Epeirogenic movements during the waning Asturian orogenetic phase (Upper Westphalian D) caused the development of intramontane basins, and these were filled with coarse- and fine-grained clastic sediments and coal beds, during and after which they were folded, particularly during the Saalic orogenetic phase (de Sitter & van den Bosch, 1968). Therefore, we agree with Virgili and Corrales (1966) that there is a great similarity between the classic Tertiary alpine molasse deposits of Switzerland and Germany and the Carboniferous Hercynic molasse of the present area. The similarity with the Eastern Alps, where molasse deposits occur in intramontane basins, is still greater. However, the Cea Group sediments are not everywhere developed in a molasse facies. The Stephanian of the Pisuerga basin, the easternmost part of the exposed Paleozoic of the Cantabrian Mountains, is partly developed as marine turbidites (Nederlof, 1959; Reading, 1970; van de Graaff, 1971). Here we find a transition from flysch to molasse (Reading, 1970), just as occurs locally in the Western Alps (Trümpy, 1960).

Detailed stratigraphical work by Wagner et al. (1969) led to the proposal to introduce a new stratigraphic stage, the Cantabrian Stage, to be distinguished from the Stephanian. The Cantabrian Stage is based on a sequence of strata, 2,000 to 3,000 m thick, younger than Westphalian D and older than Stephanian A.

According to Wagner et al. (1969), both the Upper Westphalian D plus Cantabrian sequence, as well as the Stephanian sequence proper, are unconformable successions representing separate post-orogenic sequences. These sequences consist of conglomerates in the lower part and coal measures in the upper part. In the Magdalena basin, in the western part of the area, several fining-upward sequences, consisting of conglomerates at the base up to coal seams at the top, are easily observed and can serve as examples during field trips.

The Cantabrian sequence in the type locality, near the village of Tejerina, shows conglomerates with a thickness of nearly 600 m at the base, followed by 45 m of marine mudstones and sandstones succeeded in turn by another almost 600 m of coal measures photo 1 (Wagner et al., 1969). The coal measures consist of fining-upward sequences with lenticular bodies of sandstones at the base and coal seams at the top.

The quartzite boulders in the conglomerates show higher roundness values than the sandstone and limestone boulders. Therefore, it is presumed that these boulders represent reworked elements from an older conglomerate. Older conglomerates are known from Mt. Curavacas and the surrounding area; these thick sequences of conglomerates and pebbly mudstones record earlier Westphalian movements.

Helmig (1965), Evers (1968), Wagner et al. (1969), and Wagner (1970) described the cyclothems on the basis of stability (coal = relative stability) versus subsidence (shale, sandstone = relative subsidence). These authors adhere to a theory of diastrophic control: alternation of periods of rapid and periods of slow subsidence. Van den Bosch (1969), prefers the assumption, suggested by the present author, that cyclothems may represent successive stages in complex systems of stream channels, flood plains, and backswamps, the successions being the result of the shifting of river systems.

The more conglomeratic sequences, frequently showing pebble imbrication, are fining-upward sequences with conglomerates at the base, overlain by cross-bedded sandstones; they point to a deposition by "torrential floods which dropped their load in intramontane valleys largely as alluvial cones" (Reading, 1970).

Sedimentological investigations of a red-bed sequence of Stephanian B + C age by Oele and Mabesoone (1963) led to some conclusion concerning the nature of the source area. Most of the conglomerates consist of angular limestone pebbles and a clayey to sandy matrix. The presence of 20 to

25% kaolinite in the matrix points to an acid environment of the soils on the uprising mountains that supplied the sediments. The red clayey and silty hematitic matrices of the conglomerates must have been derived from a cover of red soil in the source area, formed in a warm climate. The pebbles were transported by torrential streams; the occurrrence of plant debris "preserved and covered rather than oxidized" (O e l e & M a b e s o o n e, 1963) points to a rapid sedimentation. The clayey and silty character of the matrix may also indicate that "from time to time the current velocities decreased to zero and ponds and marshes were formed. Plants could grow up, and sieve out more silty and clayey components from the passing suspension" (O e l e & M a b e s o o n e, 1963).

The sedimentological analyses of the post-orogenic Carboniferous sediments in the Cantabrian Mountains gave results with respect to facies and climatic conditions identical to those obtained by N a g t e g a a l (1969) for the post-Hercynian continental Westphalian-D deposits of the Central Pyrenees.

Important for the reconstruction of the depositional environment is the occurrence of a marine transgression in part of the Cantabrian area during the time that continental sedimentation continued elsewhere. This feature and the occurrence of coal measures in fluviatile sequences in the continental area constitute the most important divergence from the environments of deposition of the younger clastic wedges to be described below, in which marine intercalations do not occur.

PERMIAN SEDIMENTS

With the advent of the Permian, conditions had completely changed in the Cantabrian Mountains and their surroundings. With the last folding, the intramontane molasse basins of the Stephanian had been incorporated into the folded Paleozoic mountain massif, which from then on was long to be affected only by epeirogenic and fault movements. Also, as we will see, the climate had changed.

The coarse lower part of the Mesozoic sequence has often been referred to as Permo-Triassic, because the deposition was thought to have already started in Permian times (C i r y, 1939; R a t, 1959). The Permo-Triassic formations lie in a semicircle around the eastern termination of the Paleozoic core and form a conspicuous cuesta, from which tongues extend westward in the Peña Labra (2018 m), Peña Tres Mares (2175 m), the Valdecebollas (2139 m), and in a relatively low-lying zone (1000 m) along the southern border (map in d e S i t t e r and B o s c h m a, 1966) (photo 2).

Photo 2
Cuesta of E-dipping Triassic sandstones; dipslope at Peña Tres Mares (altitude 2175 m).

The first to separate a presumably Permian sequence from the Triassic was P a p a (1964), who reported on a 27 m thick series of pink clays and breccias underlying the coarse-grained Triassic rocks in the area east of Cervera de Pisuerga and who assigned a possibly Permian age to them. A more detailed description has been given by M a a s (1968), whose report on the sedimentology of the Carboniferous and post-Carboniferous rocks of the Peña Labra area refers to a sequence of sediments, unconformably overlying the intensively folded Carboniferous rocks and in its turn unconformably (15°) overlain by the conglomeratic Triassic series (photo

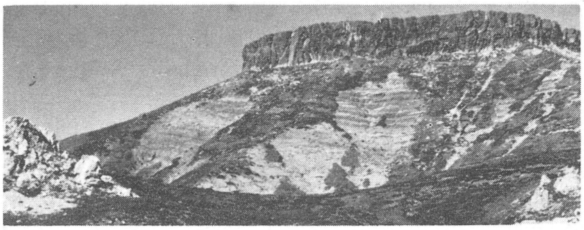

Photo 3
Peña Labra (altitude 2018 m) as seen from near Piedrasluengas pass (1313 m). Carboniferous limestones (left), unconformably overlain by Permian silts and tuffaceous breccias, in turn unconformably overlain by an almost 100 m thick layer of Triassic conglomerates.

3). The former sequence, called the Labra Formation, after the Peña Labra, is post-orogenic and pre-Triassic and is, from its stratigraphical position, most probably of Permian age. It is about 900 m thick and consists mostly of breccias, siltstones, sandstones, and some conglomerates. The polymict breccias consist of tuffaceous rocks[2]) and limestone fragments; sorting is poor and organic remains were not found. B u d d i n g (oral comm. 1970), who started sedimentological work on the Permo-Triassic successions in 1970, considers the volcanic character of the Peña Labra sequences to be even more dominant, the lower part being tuffaceous and the upper part showing a fluviatile character. Further to the north, the volcanic aspect is less pronounced and the sequence shows fluvial aspects throughout. The tuffs may be related to the post-orogenic volcanic necks and sills occurring in the Paleozoic of the Cantabrian Mountains.

The depositional environment of the Permian layers, as inferred by M a a s (1969), is one of short transport in small intramontane basins, with deposition of fine-grained silty material in shallow lakes, and erosional activity resulting in the formation of channels. Breccias of volcanic tuffaceous rocks indicate post-Hercynian volcanism, whereas the occurrence of limestone breccias points to alluvial fans of detritus of older Paleozoic rocks, deposited under the prevailing arid conditions.

THE TRIASSIC CLASTIC WEDGE

The thickness of the Triassic sequences, which consist mainly of red beds, is about 850 m in the Peña Tres Mares area, east of the Paleozoic core, and less than 200 m at the southern border (P a p a, 1964; S m i t, 1966; M a a s, 1967).

The sequence consists of a coarse-grained, conglomeratic, lower part overlain by a finer-grained upper part consisting of sandstones and siltstones. The upper part, according to R a t (1959), passes laterally into clayey sediments with a Keuper facies, but whether they coincide in time with the Germanic Keuper cannot be said.

We will first consider the conglomeratic part.

The conglomerates

The thickness of the conglomerates is greatest in the Peña Labra section where it is 80 m, thinning to 20 m toward the NW, to 10-15 m toward the NE and to 6-20 m toward the S. There seems to have been a centre of distribution in the Peña Labra area from which coarse clastic wedges radiated towards the NW, NE, and SE. In addition the pebble sizes in the Peña Labra region are larger (up to 30 cm) and the matrix is a deeper red than farther to the SE. In the southern zone roundness values are lower in the westernmost part than in the eastern parts, and the maximum length of the pebbles also shows a decrease from west towards east. Furthermore, the pebble size also decreases upward, being several decimeters in the lower part and less than one decimeter in the upper part.

The basal part is developed in thick, continuous layers of conglomerate with occasional sandstone and shale layers indicating the bedding (photo 4). Higher up, the conglomerates and sandstones show wedging, with conglomeratic channel fills. The channels are relatively wide: measurements gave width/depth indices (x 100) of about 700 in the northern area and up to 1,500 in the southern. These values are much larger than those found by N a g t e g a a l (1966) in Oligocene piedmont fans in the eastern Pyrenees, where the values range from 125 to 575.

The coarse-grained deposits have all the characteristics of alluvial fans, whereas farther away from the depositional centre, sands and silts were laid down. Since measurements of paleocurrent directions in the

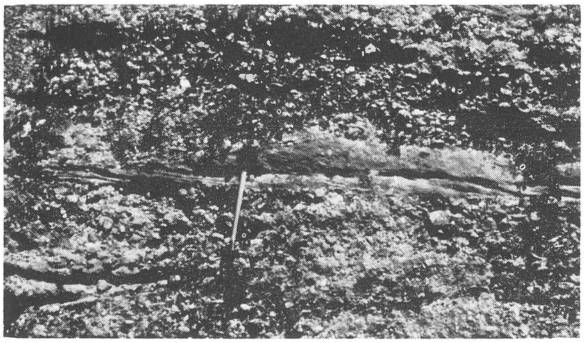

Photo 4
Massive layers of poorly sorted, structureless conglomerate interbedded with SE-dipping bedded sandstone; Triassic, S of Valdecebollas.

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[2]) The occurrence of volcanic material in the lower part of the Permo-Triassic has already been mentioned by C i r y (1939) and N o s s i n (1959).

sandstones, although not numerous point to a supply from W or NW, the alluvial fans of this area must have had their apical parts in the W, where no Trias has been preserved. A conspicuous fan must have had its centre near the Peña Labra, from where the conglomerates thin out radially, and have been active for a long time while the basin slowly subsided. The poorly sorted, mostly coarse-grained character of the sediments shows that transportation did not take place over long distances.

The deposition on the apical part of the fan may have derived from occasional heavy floods, as suggested by the great and constant thickness of the lower conglomerate layers, their poor sorting, and their occasional grading. Higher up, in the series, channeling becomes more frequent and the transporting mechanism becomes more normally fluvial, as is also shown by imbricated pebbles.

The fining-upward character of the Triassic sequence as a whole may indicate either a waning of the supply of coarse pebbles caused by a diminution of vertical erosion in the source area, or a gradual westward extension of the area of deposition, so that the relevant area at the eastern end of the Cantabrian mountains came to lie farther and farther away from the source area, or, in other words in the distal parts of the fans, to which only sand and silt were transported.

It should be realized that Permian and Triassic deposits, which now strike out at the eastern end of the mountain chain, may have covered the Cantabrian Mountains much farther to the W. How far is not known. Parts of this cover may have still been present in early Tertiary times, since sandstone pebbles very similar to Triassic sandstones have been found in Lower Tertiary conglomerates along the southern mountain border (Mabesoone, 1959).

The composition of the pebbles shows a remarkable feature. They mainly consist of quartzite and vein-quartz, but a few are sandstone and chert; the matrix consists of coarse-grained subangular quartz grains. Thus, limestone pebbles are absent, contrary to what we have seen in the Stephanian and Permian conglomerates and breccias and what we shall find in the Older Tertiary. This is the more remarkable since the Trias locally overlies Carboniferous limestones. An explanation is difficult to give. It could be that the limestone pebbles were destroyed during transport, even though the transport distance was short, or that the outcrops of limestone were covered by thick residual clays. Another possibility is that parts of the Cantabrian Mountains were protected from erosion by a cover of Permian through which only the higher quartzite ridges protruded and were available as source rock for the Triassic conglomerates. This is, however, purely conjectural.

The sandstones and siltstones

In the transitional beds between the conglomeratic lower part and the sandy to silty upper part of the Triassic, we find fluvial sequences with a thickness of one to two metres and consisting of coarse-grained, conglomeratic, channel fills, occasionally with clay pebbles, fining upwards into sand- and siltstones with well-developed parting lineation. These sequences can be observed particularly well along the motor road climbing from Reinosa to near the Peña Tres Mares (photo 5) and in the Nansa-valley. Conglomeratic sandstones showing floating pebbles in a coarse sandy matrix are also found.

In the sandstones cross-bedding is common; trough-fill cross-stratification occurs especially often in the sandstones directly overlying the conglomerates (photo 6): tabular cross-stratification is found in the somewhat finer-grained upper part of the sandstones. Both stratification types suggest deposition under tranquil flow conditions. Although the fining upward of sediment implies a waning current, McGowen and Garner (1970) recently showed that trough-fill stratification and foreset cross-stratifi-

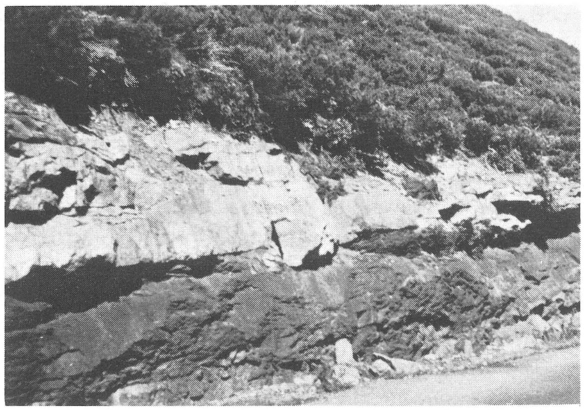

Photo 5
Fining-upward fluvial sequences in Triassic sandstones and siltstones along the highway between Reinosa and Peña Tres Mares.

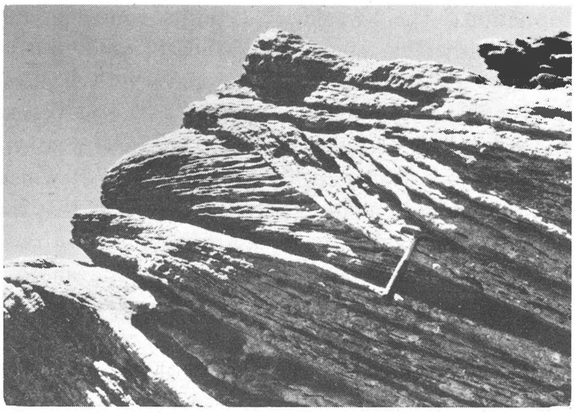

Photo 6
Cross-bedded coarse-grained sandstones in Triassic fluvial sequences at Peña Tres Mares (altitude 2175 m).

cation may "form concurrently under similar flow conditions".

The occurrence of parting lineation and the presence of mica flakes along the bedding planes in the fine-grained sandstones and siltstones gives them the characteristic appearance of flagstones. Sorting of the sandstones is in general poor: So-values (according to Trask) in 15 samples vary from 1.37 to 8.12 (P a p a, 1964).

The environment of deposition seems to have been one of extensive flood plains at the distal ends of the alluvial fans, where the braided rivers of the fans empty into interfluvial plains with dominant silt deposition. Thin, fining-upward fluvial sequences mark the inflow of relatively coarse-grained material into the interfluvial-plain environment.

The petrographic composition of the sandstones is as peculiar as that of the conglomerates: quartz is the main constituent; the second place is occupied by feldspar with 10 to 40% (much microcline, some plagioclase and orthoclase), whereas mica (muscovite) and chlorite occur in only minor quantities. The provenance of the feldspar is difficult to account for, but conceivably it was supplied as phenocrysts by renewed volcanism, or derived from the nearest exposed granites, which are, however, at a distance of more than 200 km to the W, or from conjectured nearer-by granites hidden below the Tertiary in the SW or the sea in the NW.

The heavy-mineral composition, on the other hand, is not abnormal. The most resistant minerals – tourmaline, zircon, rutile, anatase, and brookite – are the most abundant; little staurolite, andalusite, or barite is found, and seldom garnet, augite, hornblende, epidote, or alterite.

The siltstones and finest-grained sandstones are thought to have been deposited in the bajadas. The plain must have undergone occasional flooding, as indicated by the following observations. Wave and/or current ripples are found in the fine-grained sandstones; in many cases a definite distinction between them could not be made in the field. Mudcracks are often found in the topmost silty layers. Loadcasts at the contact of silts and clays with overlying sands or coarser grained sediments may indicate that the latter were rapidly deposited upon water-logged silts and clays. The occurrence of unidentifiable plant remains in the sandstones, many worm tracks and animal footprints (with five toes; Chiroterium?) in the siltstone, together with the wave ripples, also indicate a backswamp environment.

On the other hand, the flood plain must also have witnessed long dry periods with evaporation of the standing water (playa environment). This is shown by the occurrence of one metre-thick layers of gypsum, and of bipyramidal quartz grains, which according to F ü c h t b a u e r (1950) and G r i m m (1962) can originate from a silica solution in a salinary environment. The subsoil must even contain halite, since names of villages on the southern mountain border, such as Salinas, indicate the presence of salt, which was exploited here in former times. Farther to the E follow thicker evaporite layers that gave rise to the well-known salt diapirs.

The inferred climate must have been semi-arid; the predominance of illite among the clay minerals supplied by the source area is not at variance with this conclusion, since it is resistant in such an environment. The preservation of feldspar in the sands is also in accordance with a semi-arid climate.

The rocks of the Triassic sequences are generally red to pink, the colour being more intense when the rock is finer grained. On the alluvial fans, however, streaks and lenses of coarse white quartz sand occur within thick conglomeratic banks that alternate with thick units of white coarse-grained, micaceous, flaggy, cross-bedded quartzite.

The colouring of the deposits by hematite must be postdepositional, since most of the sand grains in the red sandstones have a skin of iron oxide, and this skin is not worn, as are many of the sand grains. In the Triassic of the Pyrenees too, hematite was mainly precipitated at an early diagenetic stage (N a g t e -

g a a l, 1969). Locally, the coulour later changed to green.

Later diagenetic processes in the sandstones are the secondary growth of quartz grains as shown by dust rings, and the local occurrence of a carbonate cement. The carbonate cement was deposited after the secondary growth of quartz.

Toward the end of the deposition of the Triassic there is no evidence that the Cantabrian Mountains still existed as such. Parts may have been covered by Triassic deposits and thus turned into a depositional area, and what remained uncovered may have had a subdued relief.

This situation will have persisted in Jurassic and Lower Cretaceous times. Marine Jurassic beds are only known from the eastern end of the mountain range, where they overlie the Triassic, and Lower Cretaceous deposits, partly in a fine-grained continental facies (R a t, 1962), are found still farther away to the east.

EVIDENCE FROM UPPER CRETACEOUS DEPOSITS

The continental deposits of the Upper Cretaceous again supply evidence pertaining to the conditions of the Cantabrian Mountains. These deposits crop out a narrow strip along the southern border of the mountain range, often tilted or in a steep position as a result of Tertiary movements.

The Upper Cretaceous series represents a transgressive sequence, starting with coarse-grained terrigenous rocks in continental facies, usually referred to as Wealden facies, fining upwards and passing, via transitional beds, into a marine sequence of Upper Cretaceous age. The marine sequence has a diachronous lower boundary, being of Albian age in the Burgos area, east of the area under study, and of Maastrichtian age in the west, where near la Robla the marine deposits wedge out (C i r y, 1939; E v e r s, 1968).

According to C i r y (1939), the basal kaolinitic gravels would indicate a denudation phase of the Hercynian Cantabrian Mountain chain. C a r b a l l e i r a (1969) and v a n d e G r a a f f - T r o u w b o r s t (1970), reporting on the Cretaceous beds near Cervera de Pisuerga, also describe Cretaceous conglomerates in continental facies as having derived from the Carboniferous and Triassic formations. The "Wealden" deposits consist of the least weatherable components (quartz sand, quartz pebbles) and contain kaolinitic clays with lignites. This would mean that the source area had passed through a long period of intensive chemical weathering. But work being done by J o n k e r (1970), which will be published in due course, has revealed, that the deposits in Wealden facies, overlying the basal conglomerates, must have derived from quite another source area, probably the northwestern Spanish and/ or northern Portugese granitic area to the west and southwest, mainly on account of paleocurrent measurements, the lack of limestone pebbles, and of the mineralogical composition of the sandy sediments: dominant quartz, many grains with a skin of kaolinite and a high content of muscovite. These deposits were laid down in fluvial and lagoonal environments and preceded the Upper Cretaceous marine trangression.

E v e r s (1968) introduced the name Voznuevo Formation for these "Wealden" deposits. The formation is 150 to 550 m thick and consists mainly of multicoloured sandstones with gravel lenses and lignitic clay. The quartz pebbles in the conglomeratic layers are generally coated purplish-red by a hematite film. Conglomerates with intercalations of sandstones and lenses of red claystone are interpreted as alluvial fans.

C a r b a l l e i r a (1969) distinguished three formations in the Cretaceous sequence, exposed near Cervera de Pisuerga:

a. Terrigenous sediments of Wealden facies; a fining-upwards sequence of coarse-grained cross-bedded quartz sands, with a kaolinitic matrix in the basal part, to micaceous silts and clays with plant remains in the upper part. V a n A m e r o m (1965) studied pollen and spores from these deposits sampled in the area between Boñar and La Robla, and established an Upper Cretaceous age. Therefore, this series "only deserves the term Wealden for their facies and not for their time of sedimentation", being of Cenomanian to Turonian age (v a n A m e r o m, 1965).

b A transitional facies from terrigenous, detrital sediments to glauconitic fossiliferous limestones, and

c. The limestone facies of the Upper Cretaceous transgressive sequence, closing the Cretaceous series.

The base of the Wealden rocks becomes younger

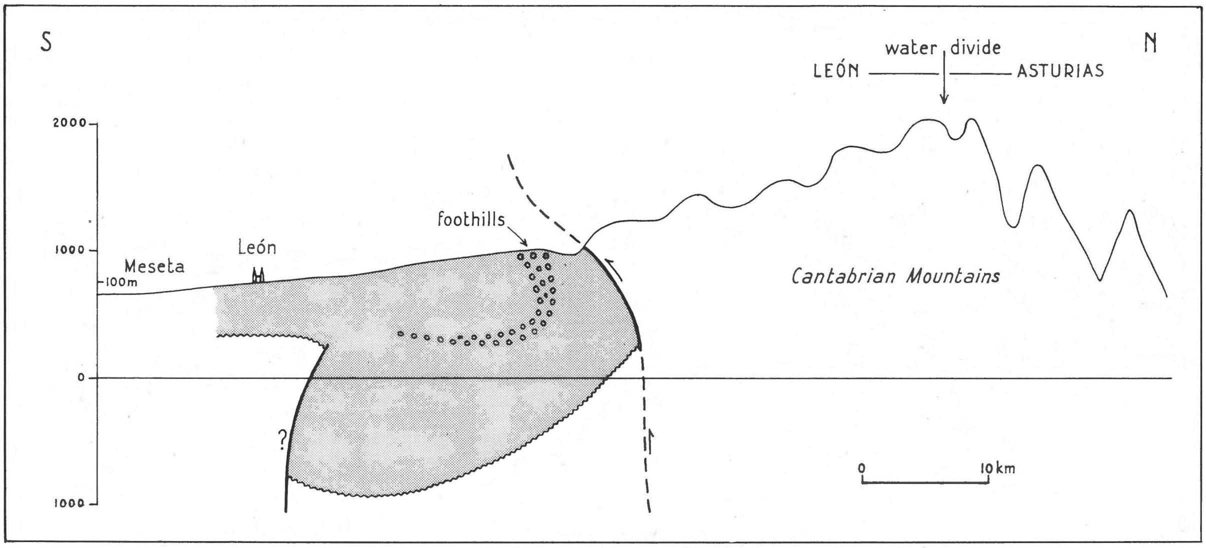

Fig. 2
Cross-section of the Cantabrian Mountains and the Duero Basin, the greater part of which was filled by clastic sediments derived from the Cantabrian Mountains (modified from de Bruyn and Evers, 1970).

towards the west, as noted by C i r y (1940), R a t (1959), and v a n A m e r o m (1965). The conformable superposition and the continuous deposition passing from the terrigenous sediments of Wealden facies into the marine limestones led C a r b a l l e i r a (1969) to suggest that the Wealden deposits belong to a transitional environment possibly deltaic. More data will have to be collected, however, to prove this. The occurrence of detrital, terrigenous components in the uppermost Maastrichtian sediments points to a beginning regression and the development of a Garumnian facies (E v e r s, 1968).

Whatever the source area of the Upper Cretaceous deposits may be, the present Cantabrian Mountains can at that time only have been a low area over which the Cretaceous deposits transgressed, at least in marginal zones if not everywhere. This is shown by the occurrence of pebbles of Upper Cretaceous limestone in the Lower Tertiary clastic wedge.

TERTIARY CLASTIC WEDGES

In Lower Tertiary times a new chapter began in the history of the Cantabrian Mountains as source area of clastic sediments, and clastic wedges of great volume were from this time on deposited in the foreland basin (fig. 2, 3). – Continental sediments cover an immense area in the Duero Basin south of the mountain chain. The Tertiary sediments discussed in this section were laid down after the Cretaceous transgression in the Cantabrian area and are considered to be deposited at the northern border of this basin, (fig. 4).

The Lower Tertiary sequence dips 10-20° southward except for a belt only a few hundred metres wide where the rocks are in a steep and occasionally even overturned position.

Stratigraphically, the Tertiary clastic wedge consists of:

(a) The Vegaquemada Formation, sandstones and siltstones, about 800 m thick in the Rio Porma Valley, conformably overlain by and laterally passing into
(b) the conglomeratic Candanedo Formation, which is about 1,000 to 1,500 m thick. The Candanedo Formation in its turn is unconformably overlain by
(c) the Vega de Riacos Formation (E v e r s, 1968), or Riacos Formation (v a n d e n B o s c h, 1969), a name derived from the Vega de Riacos facies introduced by M a b e s o o n e (1959).

The Vegaquemada Formation is characterized geo-

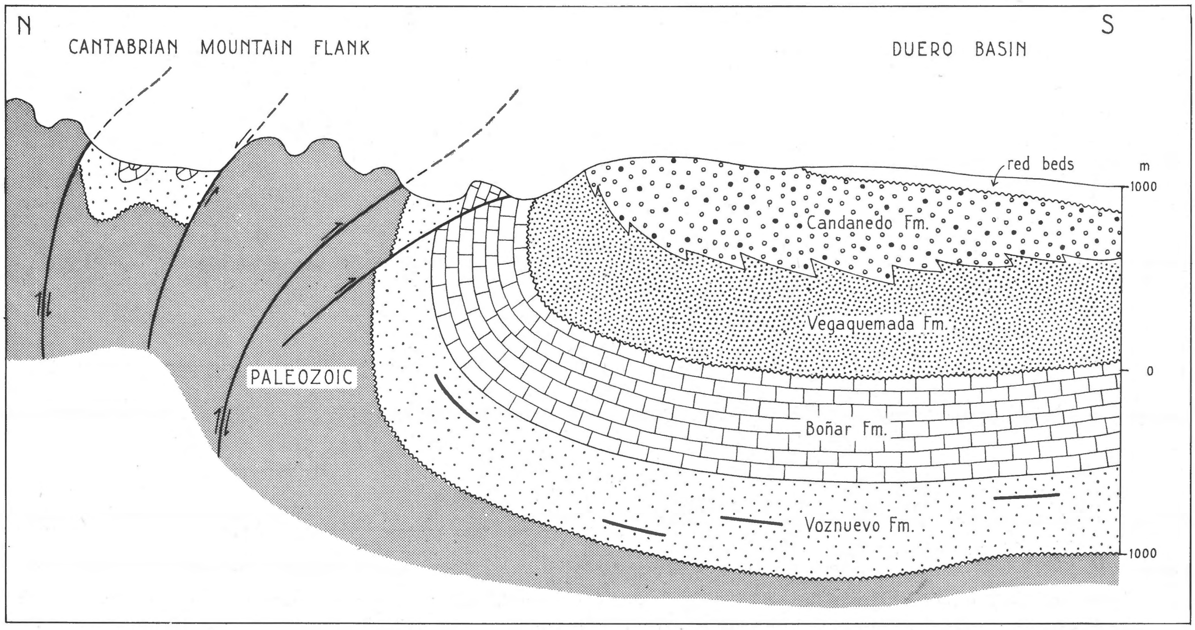

Fig. 3
Porma section; modified after de Bruyn and Evers (1970).

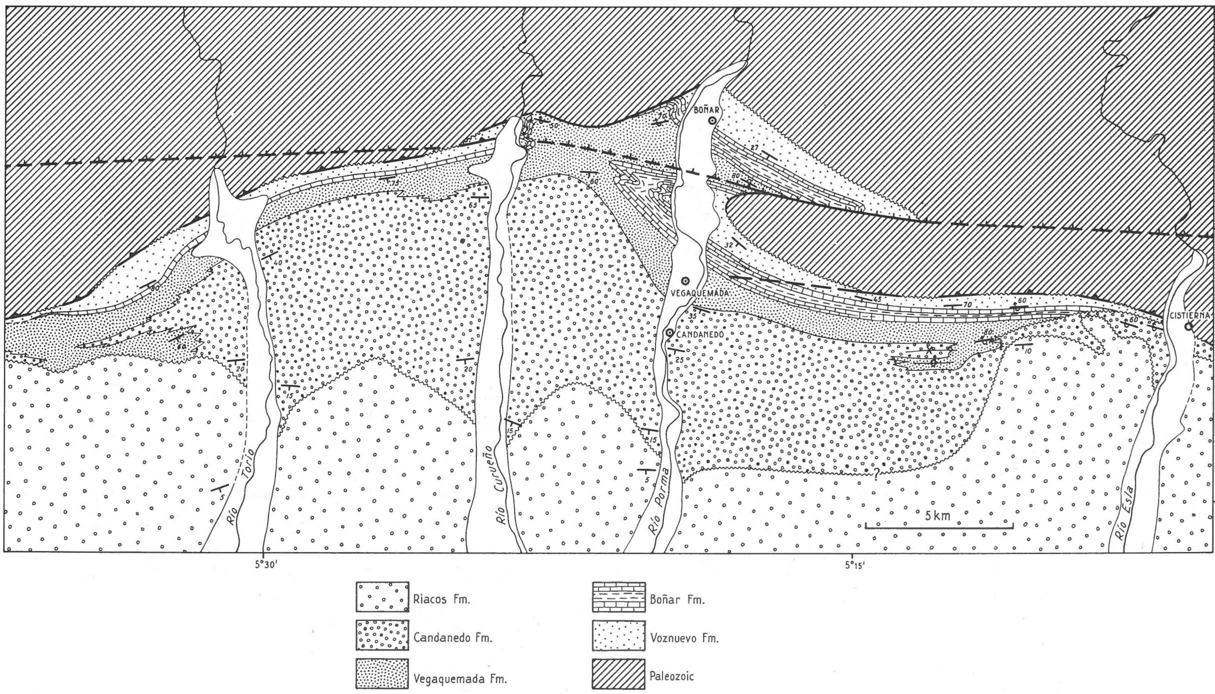

Fig. 4
Tertiary clastic-wedge sediments around Rio Porma and Rio Curueño (modified from de Bruyn and Evers, 1970, after data from Kuyp, 1969).

Photo 7
Valley of Porma River, flowing towards the south (left), follows dip of E-W striking sandy Vegaquemada Formation (in depression) and conglomeratic Candanedo Formation (hills with cuesta in background).

morphologically by the occurrence of badland erosion; its relief contrasts sharply with the cuesta formed by the overlying conglomeratic Candanedo Formation (photo 7). The topographic depression between the mountain area in the north and the coarse-grained Candanedo Formation in the south is caused by the highly erodible Vegaquemada Formation, consisting mainly of fine-grained sandstones and siltstones. The Riacos Formation, characterized by red beds, has a more horizontal position and forms the "Meseta" landscape of the area toward the south.

The *Vegaquemada Formation* overlies the Upper Cretaceous limestones with a small angular (about 4°) unconformity (C i r y, 1939; K o o p m a n s, 1962; K u y p, 1969).

The lower part of the Vegaquemada Formation consists of unfossiliferous sands, silts, and clays. A section along the Porma River shows fluvial sequences, usually less than one metre thick, each consisting of channeling sandstone, fine sand, and silt, with variegated, mostly reddish colours. Conglomerates may form the basal parts of the fluvial sequences; these conglomerates show poor sorting, and no imbrication or any other sedimentary structure were observed. The topmost clayey parts of these sequences occasionally show red mottled soils with a vertical parting. Limnic limestone layers, up to ten centimetres thick, occur at the top of some of these sequences.

Various authors consider that the deposition of this formation in a continental environment began when the upheaval of the neighbouring Cantabrian Mountains had just started and only hills with outcropping Cretaceous formations had begun to erode (E v e r s, 1968). These derived sediments, the "grès de las Bodas" of C i r y (1939), form the fine-grained part of the Vegaquemada Formation. The fact that so many elements known from the Cretaceous formations are found, points to a supply with at least a northern component. The heavy-mineral assemblage with predomination of tourmaline, zircon, and rutile, and significant percentages of staurolite and andalusite recalls the continental Cretaceous Voznuevo Formation, from which it must have partially derived.

Toward the top of the formation the sands become coarser and contain gravel lenses with current bedding (E v e r s, 1968). Apparently, the transporting capacity of the rivers coming from the source area gradually increased until it reached a maximum during the deposition of the Candanedo Formation.

Chronostatigraphically, the position of the Vegaquemada Formation is rather uncertain. C i r y (1939) mentions an Upper Eocene age, M a b e s o o n e (1959) an Oligocene age; others give a less precise age and just mention Paleogene (E v e r s, 1968). The upper parts of the Vegaquemada and Candanedo Formations show lateral interfingering so that these two deposits must be time-equivalent.

The *Candanedo Formation* consists of thick conglomerate beds and subordinate sandstone layers of a reddish-brown colour. The rather high content of elements larger than 256 mm led M a b e s o o n e (1959) to classify these deposits as boulder conglomerates; they even contain boulders of more than 1 cubic metre. In the eastern part (M a b e s o o n e, 1959) the conglomerates consist mainly of limestone pebbles derived from the Cretaceous limestones. Paleozoic pebbles are almost absent, whereas farther to the west the pebbles are mainly quartzites, sandstones, and, up to about 30%, Paleozoic limestones (K u y p, 1969) (photo 8). This means that during the deposition of the conglomerates the eastern part of the Cantabrian Mountains, at least near their southern border, was still completely covered by the Cretaceous limestones now forming only a narrow, steeply dipping strip south of the range. This eastern part of the Cretaceous limestone, which here ranges from the Turonian to the Maastrichtian, is several hundreds of metres thick; yet a considerable surface was needed to supply the necessary pebbles to a conglomerate fan with a thickness of about 1,000 m. The quartz of the matrix and the sandy intercalations could have come from deep valleys cutting through the limestone and

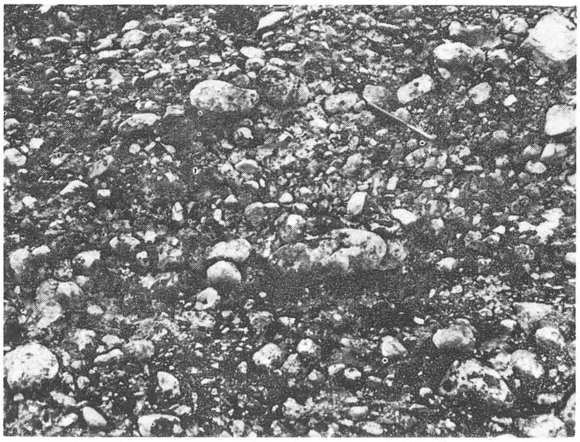

Photo 8
Poorly sorted conglomerate at Candanedo Formation in the Porma valley.

reaching down as far as the Cretaceous sands.

With such a cover of Cretaceous limestone on what is now the mountain area, however, it is difficult to visualize how the sands of the Vegaquemada Formation could have come from the "Wealden", which was still hidden under the limestone. Were there already valleys cutting through the limestone, or did these sands come from more distant parts of the mountains lacking limestone or from the surmised Garumnian on top of the limestones?

In the western section the situation was different. There, the thin Cretaceous limestone layer had already disappeared from the present mountain area; the "Wealden" would also have been removed, meanwhile supplying sands to the Vegaquemada Formation. The Paleozoic core was thus laid bare and became subject to erosion.

The transportation mechanism can be deduced from the following observations. The conglomerate layers have constant thicknesses of 3 to 5 metres over relatively long distances. They show graded cycles less than one to two metres thick; sorting is very poor. Along the borders of the conglomerate fans, layers of coarse sandstone, up to half a metre thick, are intercalated; they can be followed over hundreds of metres. Grading is also present here; imbrication was observed in the southern and western parts, where a provenance from the NE was inferred. The pebbles are fairly well rounded, the limestones being more rounded than the quartzites (roundness index $\frac{r}{R} \times$ 1000 for the quarzites 580 against 825 for the limestones).

It follows that the conglomerates were laid down, during occasional floods, by heavily laden torrential streams which deposited their charge in thick layers. In the mountain area, these rivers must have eroded narrow valleys in which the pebbles could reach a considerable degree of roundness. The climate was, according to M a b e s o o n e (1959), warm and fairly dry.

From K u y p ' s (1970) investigations, especially from his and E v e r s (1968) maps, it is clear that the Candanedo Formation and the Vegaquemada Formation are different facies of a single alluvial fan and piedmont environment. The Candanedo Formation represents the apical part of alluvial fans of torrents coming from the mountain chain, whereas the Vegaquemada Formation was deposited in the peripheral part of the fans.

The deposition of the coarse Candanedo conglomerates must have been the consequence of an initial uplift of the mountain area at some time during the Lower Tertiary. Afterwards, before the Miocene, both the Vegaquemada and the Candanedo Formations together with the Cretaceous, were tilted and, along the mountain border, brought into a steep and even overturned position during a second Tertiary orogenic phase.

The last clastic wedge by the Cantabrian Mountains is that of the Riacos Formation, probably of Lower to Middle Miocene age (Burdigalian to Lower Vindobonian, M a b e s o o n e, 1959). It is almost horizontal, although dipping slowly below younger Miocene deposits in the south, and overlies the Lower Tertiary deposits with a small angular unconformity. This formation consists of poorly consolidated red beds with quartzite conglomerates intercalated in its lower part. The formation shows a decrease in grain size away from the mountain area; the supply of the coarse-grained detritus must have occurred along the same pathways as those occupied by the present river valleys. The conglomeratic tongues in the foreland turn, however, to the SE instead of being directed to the S, as the rivers are, so that M a b e s o o n e (1962) assumed a different stream direction. On the basis of heavy minerals (especially blue tourmaline) he reconstructed a Miocene river course running ESE. As to the depositional environment, M a b e s o o n e (1962) assumes braiding rivers in a piedmont alluvial plain.

The sediments are thought to have derived from red soils in the mountain area, formed under warm humid climatic conditions. These soils were not mature laterites, since illite is the predominant clay mineral, kaolinite taking only second place. The quartzite pebbles may partially have been taken from Paleozoic conglomerates; any limestone pebbles are thought to have disappeared by solution.

During the Pliocene and Quaternary, the considerable erosion no longer produced clastic wedges, for the simple reason that there was no longer a foreland basin south of the mountain range: the foreland had become an erosional instead of a depositional area. The relief of the foreland at present consists mainly of pediment-like surfaces of different heights (P a n - n e k o e k, 1970), covered by thin films of coarse fluvial deposits.

HEAVY-MINERAL COMPOSITION OF THE VARIOUS DETRITAL SEDIMENTS

When the heavy-mineral compositions of sediments of different ages ranging from Paleozoic (isolated samples, N o s s i n, 1959), through Triassic, Wealden to Tertiary are compared, we observe the familiar feature that – in the absence of subsequent metamorphosis – the older sediments show simpler heavy-mineral assemblages than the younger ones (fig. 5). The older rocks display a dominance of tourmaline, zircon, and the minerals of the titaniferous rutile group (rutile, brookite, anatase), whereas the younger rocks show relatively high contents of metamorphic minerals. Subordinate percentages of garnet are found in the older as well as in the younger rocks. The compositional impoverishment of the older rocks has little to do with intrastratal solution; it was the introduction of new minerals during the deposition of subsequent formations that led to a more variegated assemblage of metamorphic minerals in the relatively younger sediments, especially those of Mesozoic and Tertiary age.

The Westphalian and Triassic rocks, sampled by N o s s i n (1959), show the introduction of staurolite, although this mineral was not found in the Triassic rocks by P a p a (1964) or S m i t (1966). N o s s i n (1959, p. 305) ascribed the occurrence of metamorphic minerals to the aureoles of intrusive rocks. The 45 percent andalusite found by P a p a (1964) in the Triassic rocks of the southern part of the Permotriassic dome could possibly be explained in this way. The minerals taken together as "others", embrace mainly minerals such as epidote and/or saussurite, and furthermore small percentages of all the other common heavy minerals (garnet, hornblende, pyroxenes, titanite).

From these figures it seems likely that staurolite is derived from the Hercynian mountains, although Nossin's value is the only evidence for this conclusion so far available. M a b e s o o n e (1962), however, considered the possibility that some of the staurolite in the more westerly Neogene was supplied, together with tourmaline, by rivers coming from mountains in the west. Andalusite, already mentioned for the Triassic, appears again in the Vegaquemada Formation, which may indicate that this mineral was derived from erosion of Triassic rocks (unless both deposits obtained their andalusite from a common source). The dominance of kaolinitic quartz sands among the Wealden sediments are not to be considered evidence of a derivation from the Cantabrian Mountains; these sands are a quite foreign element in the succession of sediments found along the mountains. A supply from the northwestern Spanish and/or northern Portuguese granitic area farther to the west must be considered as one possibility until additional data become available. – The heavy minerals of the Tertiary sediments seem to be derived from the Cantabrian Mountains and from the "Wealden" rocks exposed along the mountain front at the time of deposition.

L e g u e y and R o d r i g u e z (1969, 1970), however, mention the supply of andalusite, staurolite, and garnet from older Paleozoic formations, of Cambrian, Silurian, and Devonian age, in the Esla drainage area, whereas Carboniferous formations would have contained the stable minerals zircon, tourmaline, and rutile. All these minerals are considered to be reworked. It is a pity that Leguey and Rodriguez do not give more detailed information about the heavy-mineral composition and about just which rocks or soils were analysed. The heavy-minerals from the older Paleozoic rocks, as reported by them, would imply some pre-Carboniferous metamorphism and the formation of new minerals, in contrast to the stable-mineral composition found in the Carboniferous formations.

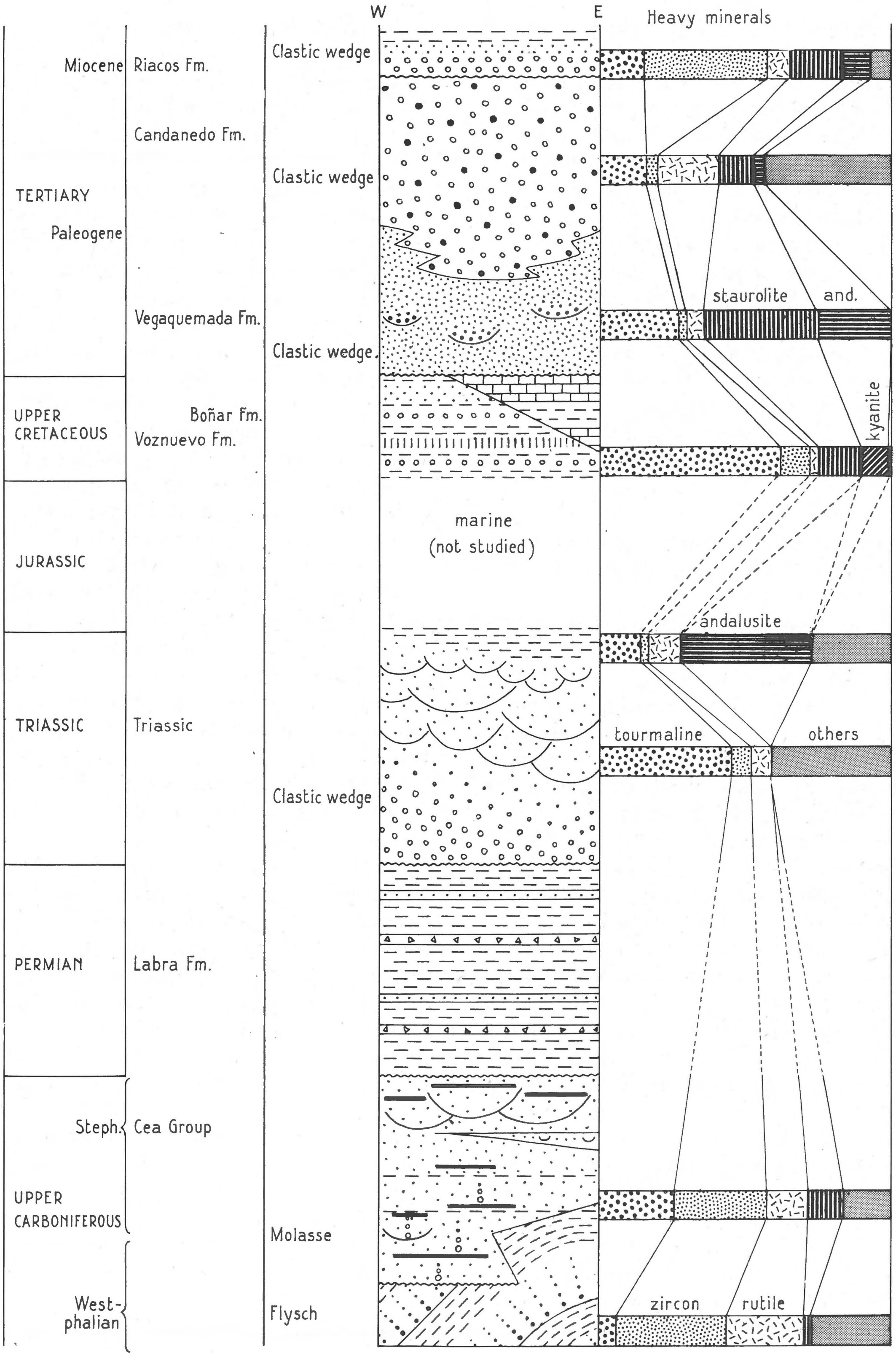

Fig. 5
Schematic lithologic column and heavy-mineral composition of Cantabrian molasse and clastic-wedge sediments; not to scale.

BRIEF REVIEW OF THE DEPOSITIONAL HISTORY

The first post-orogenetic deposits of the Cantabrian Mountains, of Westphalian D to Stephanian age and comparable to the Alpine Molasse, were formed in intramontane basins. They consist mainly of thick alluvial-fan deposits and of fluviatile sequences grading upward to coal measures. Towards the east, the formation becomes via deltaic deposits (v a n d e G r a a f f, 1971) increasingly paralic and passes into a fully marine turbidite sequence. The climate must have been warm-humid, with red soils forming in the surrounding mountains.

During the Permian, sedimentation was limited to volcanic breccias and fine-grained limnic and/or fluvial deposits.

Triassic times brought a significant upheaval of the Paleozoic Cantabrian Mountains and the formation of coarse-grained clastic wedges, deposited as alluvial fans by torrential streams, grading in outward and upward directions into finer-grained flood plains and playas. These red beds were probably formed in a warm and rather arid climate.

The Jurassic and Cretaceous probably represent relatively stable periods, in which the mountain area had a subdued relief and was even partly submerged during marine transgressions. The continental deposits of the Upper Cretaceous in "Wealden" facies were probably not supplied by the Cantabrian Mountains but from areas further to the west.

In Lower Tertiary times renewed epeirogenic uplifts of the Cantabrian Mountains led once more to the formation of extensive clastic wedges in the foreland basin, partially in the form of large alluvial fans with conglomerates up to 1000 m thick, again in a rather arid climate. The red beds of the Miocene, also with conglomerates, point to a warm-humid climate in the mountain area, whereas the foreland basin was relatively dry.

Thus, the formation of Molasse and clastic wedges was on the one hand a consequence of successive epeirogenic uplifts of the mountain chain and subsidence of the foreland basin and on the other hand of the varying environmental and climatic conditions in the areas of denudation and deposition.

TABLE 1

Heavy mineral composition of sedimentary rocks of different ages in and along the Cantabrian Mountains (in percentages).

tourmaline	14	6	26	34	48	60	14	46	63	22	26	16	15	43
zircon	50	38	32	32	5	8	2	27	10	46	3	4	42	17
rutile + anatase + brookite	10	27	14	7	5	24	12	11	3	19	6	21	8	11
garnet	8	5	6	9										
staurolite			10	6				5	15	4	39	8	18	16
kyanite									9					
andalusite		2					45			3	25	4	10	5
others	18	22	12	12	42	8	27	11		6	1	47	7	8
Size grade (in micron)	50-500	50-500	50-500	50-500	50-500	50-500	50-500	50-500	50-500	50-150	50-150	50-500	50-500	50-500
Author	Nossin (1959)	Nossin (1959)	Nossin (1959)	Nossin (1959)	Smit (1966)	Papa (1964)	Papa (1964)	Nossin (1959)	Jonker (1970)	Kuyp (1969)	Kuyp (1969)	Kuyp (1969)	Mabesoone (1962)	Mabesoone (1962)
Age	Devonian	Curavacas congl.	Westphalian	Triassic	Triassic	Triassic	Triassic	Wealden	Wealden	Vegaquemada	Vegaquemada	Candanedo	Riacos-Bernesga	Riacos-Pisuerga

ACKNOWLEDGEMENTS

The present compilation would not have been possible if I had not been given access to the unpublished M.Sc. theses on the investigations of the following students of the Sedimentary Geology Section: Mrs. van de Graaff-Trouwborst, and Messrs. Jonker, Kuyp, Maas, Papa, and Smit. I am also very grateful to Prof. A.J. Pannekoek, who rendered invaluable help by reading the manuscript and suggesting improvements.

REFERENCES

Amerom, H.W.J. van (1965) – Upper-Cretaceous pollen and spores assemblages from the so-called "Wealden" of the province of León (Northern Spain) – Pollen et Spores, 7, p. 93-133.

Birot, P. (1955) – Les méthodes de la morphologie. Paris, Presses Univ. Fr., (especially p. 105-116).

Bosch, W.J. van den (1969) – Geology of the Luna-Sil region, Cantabrian Mountains (NW Spain) – Leidse Geol. Meded., 44, p. 137-225.

Boschma, D. and C.J. van Staalduinen (1968) – Mapable units of the Carboniferous in the southern Cantabrian Mountains (NW-Spain) – Leidse Geol. Meded., 43, p. 221-232.

Bruyn, J.E. de, and H.J. Evers (1970) – Gravity survey of the NW Duero Basin (León, NW Spain) – Leidse Geol. Meded. (in press).

Cadisch, J. (1928) – Das Werden der Alpen im Spiegel der Vorlandsedimentation – Geol. Rundschau, 19, p. 105-119.

Carballeira, J. (1969) – El Cretacico del SE de Cervera de Pisuerga – Breviora Geol. Asturica, 13 (4), p. 41-45.

Ciry, R. (1939) – Etude géologique d'une partie des provinces de Burgos, Palencia, León et Santander – Bull. Soc. Hist. Nat., Toulouse, 74, p. 1-528.

Evers, H.J. (1968) – Geology of the Leonides between the Bernesga and Porma rivers, Cantabrian Mountains, NW Spain – Leidse Geol. Meded., 41, p. 83-151.

Frets, D.C. (1965) – The geology of the southern part of the Pisuerga basin and the adjacent area of Santibañes de Resoba, Palencia, Spain – Leidse geol. Meded., 31, p. 113-162.

Füchtbauer, H. (1950) – Die nichtkarbonatischen Bestandteile des Göttinger Muschelkalkes mit besonderer Berücksichtigung der Mineralneubildungen – Heid. Beitr. Min. Petr. 2, p. 235-254.

Graaff, W.J.E. van de (1971) – Three Upper Carboniferous limestone-rich high-destructive, delta systems with submarine fan deposits, Cantabrian Mountains, Spain – Leidse Geol. Meded., 46, p. 157-235.

Grimm, W.D. (1962) – Idiomorphe Quarze als Leitmineralien für salinare Fazies – Erdöl und Kohle, 15, p. 880-887.

—— (1962) – Ausfällung von Kieselsäure in salinar beeinflussten Sedimenten – Zschr. deut. geol. Ges., 114, p. 590-619.

Harpum, J.R. (1960) – The concept of the geological cycle and its application to problems of precambrian geology – Rep. 21st Session, Norden, 1960. Intern. Geol. Congress, Pt. 9, p. 201-206.

Helmig, H.M. (1965) – The geology of the Valderrueda, Tejerina, Ocejo and Sabero coal basins (Cantabrian Mountains, Spain) – Leidse Geol. Meded., 32, p. 75-149.

King, P.B. (1959) – The evolution of North America – Princeton University Press.

Koopmans, B.N. (1962) – The sedimentary and structural history of the Valsurvio Dome (Cantabrian Mountains, Spain) – Leidse Geol. Meded., 26, p. 131-232.

Krumbein, W.C. and L.L. Sloss (1963) – Stratigraphy and sedimentation (2nd ed.) Freeman and Cy., San Francisco and London.

Leguey, S. y.J. Rodriguez (1969) – Estudio mineralógico de los ríos de la cuenca del Pisuerga. III Composición mineral y su relación con la roca madre – An. Edaf. y Agrobiol., 28, p. 485-541.

—— (1970) – Estudio mineralógico de los ríos de la cuenca del Esla. II Carácteres especiales de los minerales y su relación con la roca madre – An. Edaf. y Agrobiol., 29, p. 175-192.

Mabesoone, J.M. (1959) – Tertiary and Quaternary sedimentation in a part of the Duero Basin – Leidse Geol. Meded., 24, p. 31-180.

—— (1962) – Origin of the Tertiary red beds in the Northern part of the Duero Basin (Spain) – Leidse Geol. Meded., 26, p. 93-113 and p. 233-254.

McGowen, J.H. and L.E. Garner (1970) – Physiographic features and stratification types of coarse-grained point bars: modern and ancients examples – Sedimentology, 14, p. 77-111.

Nagtegaal, P.J.C. (1968) – Scour- and fill structures from a fluvial piedmont environment – Geol. en Mijnb., 55, p. 342-354.

—— (1969) – Sedimentology, paleoclimatology, and diagenesis of post-Hercynian deposits in the South-Central Pyrenees, Spain – Leidse Geol. Meded., 42, p. 143-238.

Nederlof, M.H. (1959) – Structure and sedimentology of the Upper Carboniferous of the upper Pisuerga valleys, Cantabrian Mountains, Spain – Leidse Geol. Meded., 24, p. 603-703.

Nossin, J.J. (1959) – Geomorphological aspects of the Pisuerga drainage area in the Cantabrian Mountains (Spain) – Leidse Geol. Meded., 24, p. 283-406.

Oele, E. and J.M. Mabesoone (1963) – Origin of the Stephanian red beds in the Ocejo basin (prov. of León, Spain) – Leidse Geol. Meded., 28, p. 377-388.

Pannekoek, A.J. (1957) – Sedimentation around mountain ranges, with examples from northern Spain – Tijdschr. Kon. Ned. Aardr. Gen. 74, p. 356-372.

—— (1970) – The application of graphical methods to the piedmont relief of the Cantabrian Mountains, Spain – Zeitschr. Geomorph. Suppl. 10, p. 88-103.

Pettijohn, F.J. (1957) – Sedimentary rocks (2nd ed.) – Harper & Brothers, New York.

Rat, P. (1959) – Les Pays crétacés basco-cantabriques (Espagne) – Thèse Fac. Sc. Dijon et Publ. Univ. Dijon, 18, p. 1-525.

—— (1962) – Contribution à l'étude stratigraphique du Purbeckien-Wealdien de la région de Santander (Espagne) – Bull. Soc. géol. France (7) 4, p. 3-12.

Reading, H.G. (1970) – Sedimentation in the Upper Carboniferous of the southern flanks of the central Cantabrian Mountains, Northern Spain – Proc. Geol. Assoc., 81 (1), p. 1-41.

Rupke, J. (1965) – The Esla nappe, Cantabrian Mountains (Spain) – Leidse Geol. Meded., 32, p. 1-74.

Sitter, L.U. de and W.J. van den Bosch (1968) – The structure of the SW parts of the Cantabrian Mountains – Leidse Geol. Meded., 43, p. 213-216.

Sitter, L.U. de and D. Boschma (1966) – Explanation geological map of the Paleozoic of the southern Cantabrian Mountains 1 : 50.000, sheet I Pisuerga – Leidse Geol. Meded., 31, p. 191-238.

Trümpy, R. (1960) – Paleotectonic evolution of the Central and Western Alps – Geol. Soc. America Bull. 71, p. 843-908 (especially p. 878-880).

Virgili, C. and I. Corrales (1966) – Las series molásicas estefanienses del occidente de Asturias – Acta Geol. Hisp., (4), p. 17-21.

Wagner, R.H. (1970) – An outline of the Carboniferous stratigraphy of Northwest Spain – Congr. et Coll., Univ. Liège, 55, p. 429-463.

Wagner, R.H., F.J. Villegas, and F. Fonollá (1969) – Description of the Lower Cantabrian stratotype near Tejerina (León, NW Spain) – C.R. 6e Intern. Congr. Strat. Géol. Carbonif., Sheffield 1967, 1, p. 115-138.

Waterschoot van der Gracht, W.A.J.M. van (1931) – Permo-Carboniferous orogeny in south-central United States – Bull. Am. Ass. Petr. Geol., 15, p. 991-1057.

Unpublished M.Sc. theses, Department of Geology, Sedimentary Geology Section, Leiden State University:

Graaff-Trouwborst, T.C.M. van de (1970) – A Cretaceous section of 647 meters between Cervera de Pisuerga and Vado de Cervera (Prov. Palencia, Spain) (in Dutch)

Jonker, R.K. (1970) – Sedimentological investigations of the Voznuevo ("Wealden") Formation in the Province of León (in Dutch)

Kuyp, A.A. (1969) – Sedimentological studies of the Tertiary along the southern border of the Cantabrian Mountains in the Province of León (Spain) (in Dutch)

Maas, K. (1968) – The geology of the Polaciones – Comunidad area. Part 2: Sedimentology (in Dutch)

Papa, F. (1964) – The Bunter between Cervera and Brañosera in the northern part of the Province of Palencia (Spain) (in Dutch)

Smit, P.W. (1966) – Sedimentary petrography and environmental analysis of the Permo-Triassic deposits along the eastern border of the Cantabrian Mountains (Spain) (in Dutch)