LEIDSE GEOLOGISCHE MEDEDELINGEN, Dl. 32 1965 blz. 75-149, Preissued 20-1-1965

# THE GEOLOGY OF THE VALDERRUEDA, TEJERINA, OCEJO AND SABERO COAL BASINS (CANTABRIAN MOUNTAINS, SPAIN)

BY

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## ABSTRACT

Four Upper Carboniferous limnic coal basins in the Cantabrian mountains are described.

In the coal measures, which are known as the Cea formation and unconformably overlie the Older Palaeozoic, two sedimentary cycles are recognised. Accordingly, the unconformable sequence is subdivided into two members.

The lower one, the Carrión member, starts with quartzite conglomerates and becomes gradually finer grained upwards. It yields anthracitic coal and upper Westphalian D floras. Its maximum thickness is 1200 m.

The upper one, the Prado member, begins with limestone conglomerates and also grades to finer sediments upwards. It contains dry to fat coals and Stephanian A to B floras. Its maximum compiled thickness may be approximately 2500 m but a complete section is not found anywhere.

The Cea formation shows onlap onto the Older Palaeozoic towards the west.

The predominant structural trend in the Cea formation in the described area is east-west. A few structures with north-south axes were recognised in the Valderrueda and Ocejo basins. They are thought to have originated from differential compaction and to be the earliest structures of the Cea formation.

The east-west structures are dominated by wide, asymmetric synclines, separated by narrow zones of disturbance instead of anticlines. They have originated as a secondary effect of block faulting in the underlying Older Palaeozoic formations.

In the history of the Cea formation large east-west trending fundamental faults (terminology from de Sitter, 1956), probably separating basement blocks, play a dominant role in the deposition as well as in the deformation of the Cea rocks.

Activity along these large east-west faults in the Older Palaeozoic rocks is proved to have continued intermittently from the upper Westphalian (and earlier, Rupke, 1965) to the middle Tertiary. Thus the deformation of the Cea deposits, which is dependent on the movement along these faults, must have been a long-lasting process and not a short-lived event like, for instance, the Permian Saalic phase, as was formerly believed.

# INTRODUCTION

This study forms part of the systematic geological mapping program of the Palaeozoic core of the Cantabrian mountains (N.W. Spain), carried out by students of the Leiden University under the direction of Professor Dr. L. U. de Sitter.

Field work for this thesis was done during five summer seasons in the period between 1958 and 1963.

The Cantabrian cordillera extends from the province of Galicia in the west to the province of Burgos in the east, a distance of some 250 km. Its main divide, reaching altitudes of over 2500 m, lies about 40 km south of and runs roughly parallel to the Cantabrian coast. To the south the mountain range is bordered by the Meseta of the Duero basin, an inland plateau with elevations ranging from 1000 m near the mountains to 700 m near the Duero river.

On the southern slope of the Cantabrian mountain range there are a number of more or less isolated coal basins which range in age from uppermost Westphalian to upper Stephanian. The four of those which have been the subject of this study, the Valderrueda, Tejerina, Ocejo and Sabero basins, are all interconnected and obviously belong to the same sedimentary unit, which has been named the Cea formation.

The area in which these basins are situated lies between the Porma river in the west and the Carrión river in the east, belonging for the greater part to the province of León, except for a narrow strip along the Carrión river which lies in the province of Palencia.

The base maps used were enlargements to 1 : 25 000 scale of the Mapa de España (Instituto Geográfico y Catastrál), scale 1 : 50 000, sheets 104 Boñar, 105 Riaño, 106 Camporredondo, 130 Vega del Condado, 131 Cistierna and 132 Castrejón. Airphotos (approx. scale 1 : 35 000) were available, but for the studied coal basins they are less useful in geological respect than for the Older Palaeozoic formations. An index map of the topographic map sheets and the airphotos used is given in fig. 1.

The bulk of the writers collection of plant fossils can be found at the Musée des Sciences Naturelles in Brussels.

To Professor Dr. F. Stockmans and Mrs. Y. Stockmans-Willière, of Brussels, the writer wishes to express his gratitude for their indispensable assistance in determining his plant fossils and for their warm hospitality during his visits in Brussels.

The close collaboration with Mr. J. Rupke, co-author of the geological map presented with this paper, has been a very rewarding experience, and the writer will always gratefully remember the many discussions with him on the subject.

The critical mind and wide experience of Mr. J. F. Savage, M. Sc. has been of great value to the writer throughout the preparation of this paper.

The writer also wishes to express his gratitude to Messrs. Manuel Rodriguez Fernandez and Dr. José H. Rivas of Cistierna, and their families, for their constant friendship and hospitality during his stay in Spain.

For their hospitality and kind cooperation the writer is indebted to the following Spanish mining companies: Hulleras de Sabero y An. S.A., Hulleras de Prado, S.A., M.I.L.E.S.A., Antracitas de Besande, A. de Velilla, A. de Valdehaya, A. de San Luis, Carbones de San Isidro and Carb. de Valderrueda.

The drawings are due to Miss C. P. J. Roest, Mr. I. Sánta and Mr. H. Scheuer.

Mrs. Bartstra-Rutherford and Miss T. W. Terpstra kindly typed parts of the manuscript.

Mr. J. F. M. Mekel was helpful in correcting the Spanish summary.

The Dutch government and the Stichting Molengraaff Fonds rendered financial assistance for which the writer hereby expresses his gratitude.

*Geological setting.* — In the Cantabrian mountains virtually unmetamorphosed rocks of Precambrian to Mesozoic age are exposed.

On mainly structural grounds the region has been divided into two zones, the Leonides and the Asturides, which are separated by a fundamental linear feature, the León line (de Sitter, 1962a, b).

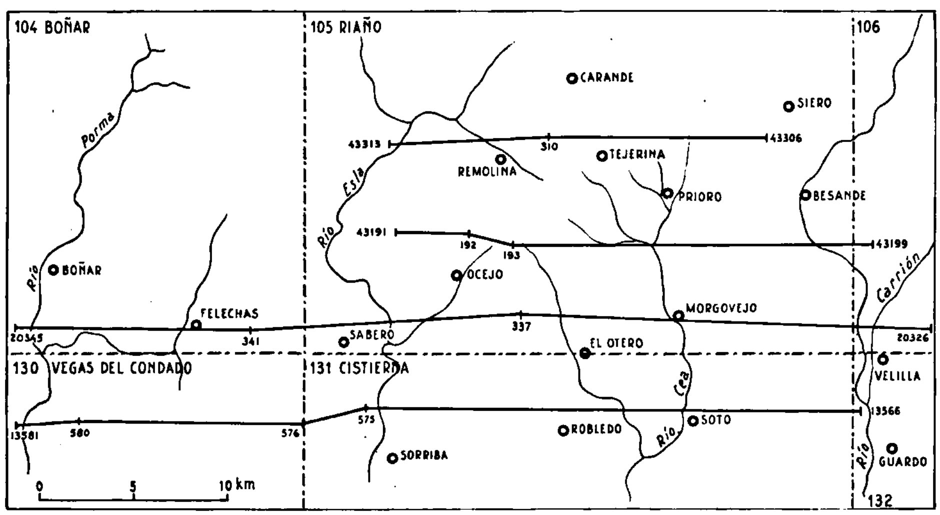


Fig. 1. Index map of the 1 : 50 000 scale topographic map sheets and the airphotos.

The Leonide zone, south of the León line, is mostly underlain by a relatively complete miogeosynclinal sequence of older Palaeozoic i.e. pre-Westphalian rocks (Rupke, 1965). Westphalian rocks are almost completely absent from the Leonides. The only younger Carboniferous rocks are of upper Westphalian D and Stephanian age and are found in the above-mentioned isolated basins. Structurally the Leonides are characterised by several northward thrusts which cause a manyfold repetition of the Older Palaeozoic sequence along a north-south section. These structures are unconformably overlain by the above-mentioned Stephanian rocks.

The Asturides are largely made up of Westphalian sediments of a paralic facies. Older Palaeozoic rocks are also present here but the sequence is stratigraphically less complete and partly of a different facies than in the Leonides. Structurally the Asturides show overturned concentric folds with east-west striking and frequently north-dipping axial planes, east- and southward thrusts and locally well-developed cleavage phenomena..

In the Leonides three distinct regional unconformities are recognized. The first one is between Precambrian and Cambrian (de Sitter, 1961a), the second occurs under the Famennian Ermitage formation (Comte, 1959, Rupke, 1965).

The third unconformity, the one relevant to this study, is found under the Cea formation. Going from east to west in the considered area the basal rocks of the Cea formation range in age from upper Westphalian D to Stephanian A–B (further west Stephanian B–C).

The structural picture of the Cea formation is dominated by broad asymmetric synclines, separated by narrow zones of disturbance in which, here and there, Older Palaeozoic crops out. This image suggests the existence of essentially rigid blocks of Older Palaeozoic rocks separated by faults, over which the Cea formation is draped.

The faults between the blocks have been active from Devonian (Rupke, 1965) to middle Tertiary times. Consequently the Cea structures, dependent as they are on these faults, have developed during a prolonged period of time and not in a short folding phase as was formerly believed.

In the following paper the author has used the term supra-basement for all the rocks older than upper Westphalian D. This term has been chosen as a shorthand expression of the concept of the special function of the Older Palaeozoic rocks as a strong though brittle mass in relation to the incompetent Cea cover.

*Previous authors.* — Little has been written on the geology of the Valderrueda basin, undoubtedly due to the apparent lack of good, continuous exposures and its complicated structure.

Mallada (1892) gave a report of a rapid reconnaissance, including a map which shows the coal beds as straight outcrops across the basin without any structural complications.

Oriol (1894) mentioned the Valderrueda basin in a summary on the coalmining activities along the southern border of the Cantabrian mountains.

The area east of the Valderrueda basin, i.e. its continuation into the Guardo-Cervera, Pisuerga and Rubagón basins, has been subject to more intensive study. The Upper Carboniferous coal measures in those basins or parts of them have been discussed by Oriol (1876), Sanchez Lozano (1906), Quiring (1939), de Sitter (1955, 1957), Kanis (1956), Nederlof (1959), Nederlof & de Sitter (1957), Wagner & Wagner-Gentis (1952, 1963), Wagner (1955, 1960), Wagner & Breimer (1958) and de Sitter (1965).

The Tejerina basin has been described by Mallada (1927) and Wagner (1962, 1964), the latter mostly discussing the palaeobotanic problems it presents. It was mapped in 1958 by Henkes (1959), whose report was not published.

On the Ocejo basin records exist from Oriol (1894), Mallada (1900) and Wagner (1959b, 1964).

The Sabero basin has been the subject of studies by Prado (1850), Hausman (1851), Oriol (1894), Mallada (1900), Wagner (1957) and Henkes (1961).

The Cea deposits to the west of the considered area, i.e. in the Matallana basin have been described by Oriol (1894), Mallada (1927), Wagner (1963), van Amerom & van Dillewijn (1963) and others.

The small occurrences of Cea sediments west of the Tejerina basin, i.e. the Salamón-Viego, Rucayo and Pontedo inliers, are the subject of a palaeobotanical study by van Amerom (1965).

A study of the possible continuation of the productive Carboniferous under the Tertiary of the Duero basin has been made by Almela (1949).

Reports of borings through the Tertiary and Mesozoic exist by Sanchez Lozano (1912) near Cervera de Pisuerga and by Zalona & Sampelayo (1943) near Boñar. The latter drill hole, however, did not penetrate any Upper Carboniferous rocks.

Cantos Figuerola (1953a, b) gave the results of geophysical investigations along the southern border of the Cantabrian mountains.

CHAPTER I

# STRATIGRAPHY

## INTRODUCTION

Rocks of Cambrian to Recent age are exposed in and surrounding the studied area. However, as the present paper deals exclusively with the productive Upper Carboniferous series, the older and younger formations will only be briefly described. For more extensive information on the older Palaeozoic, the Mesozoic and younger formations surrounding the studied area the reader is referred to the following publications.

The most detailed and recent work on the geology east and northeast of the area described in the present paper is that by Koopmans (1962) "The sedimentary and structural history of the Valsurvio dome". Leidse Geologische Mededelingen, deel 26, p. 120—232. This paper mainly deals with the stratigraphy and structure of the older Palaeozoic which in that area consists of Devonian and Carboniferous rocks up to Westphalian C (—D?) in age. Nevertheless, some attention is also given to the Cea formation on pages 162—164 and 209.

The best information available on the older Palaeozoic west and north of the area presented in this paper is provided by the following two publications.

P. Comte (1959).

In his paper Comte gives an exhaustive account of the stratigraphy of the Palaeozoic rocks of the Cantabrian mountains in the province of León, with the exception of the Upper Carboniferous. Comte's nomenclature for the Devonian and older formations has been largely adopted by later authors on this region.

J. Rupke (1965).

This work mainly deals with the geology of the Esla nappe and its related structures. It gives a detailed description of the older Palaeozoic sequence in the area. In fact, the description of this sequence given in this paper is largely based on information kindly provided by Mr. Rupke.

For the Mesozoic (Cretaceous) and younger formations which are found along the southern border of the investigated area, reference is made to the papers by Ciry (1939), Mabesoone (1959) and Koopmans (1962).

Ciry mainly describes the Mesozoic along the southern border of the Cantabrian mountains. In his paper the pages 74—280 are of special interest for the area considered in the present study.

Mabesoone gives an account of the Tertiary sediments in a part of the Duero basin immediately south of the Cantabrian mountains. He actually did not extend his investigations further west than the Carrión river, but his stratigraphic descriptions seem to be roughly valid at least as far west as the Porma river.

Koopmans mapped the Cretaceous and the Lower Tertiary rocks bordering his area to the south. He gives a brief description of these formations on pages 164—166.

## OLDER PALAEOZOIC

Most of the land surrounding the investigated coal basins is underlain by older Palaeozoic rocks ranging in age from Cambrian to Westphalian C (—D?). Therefore, it has been considered necessary to give at least a brief description of these older formations in the present paper. It is also roughly indicated where each of the described formations can be seen in contact with or near to their Cea cover. In fig. 2 the stratigraphic succession of the Older Palaeozoic rocks is represented.

The Older Palaeozoic rocks were severely deformed and eroded before the deposition of the Cea formation started. For information on their structure reference is made to the theses of Koopmans (1962) and Rupke (1965). After their main folding, which was most probably during the beginning of the Westphalian, the Older Palaeozoic rocks seem to have reacted to crustal stresses more as a rigid than as a plastic mass.

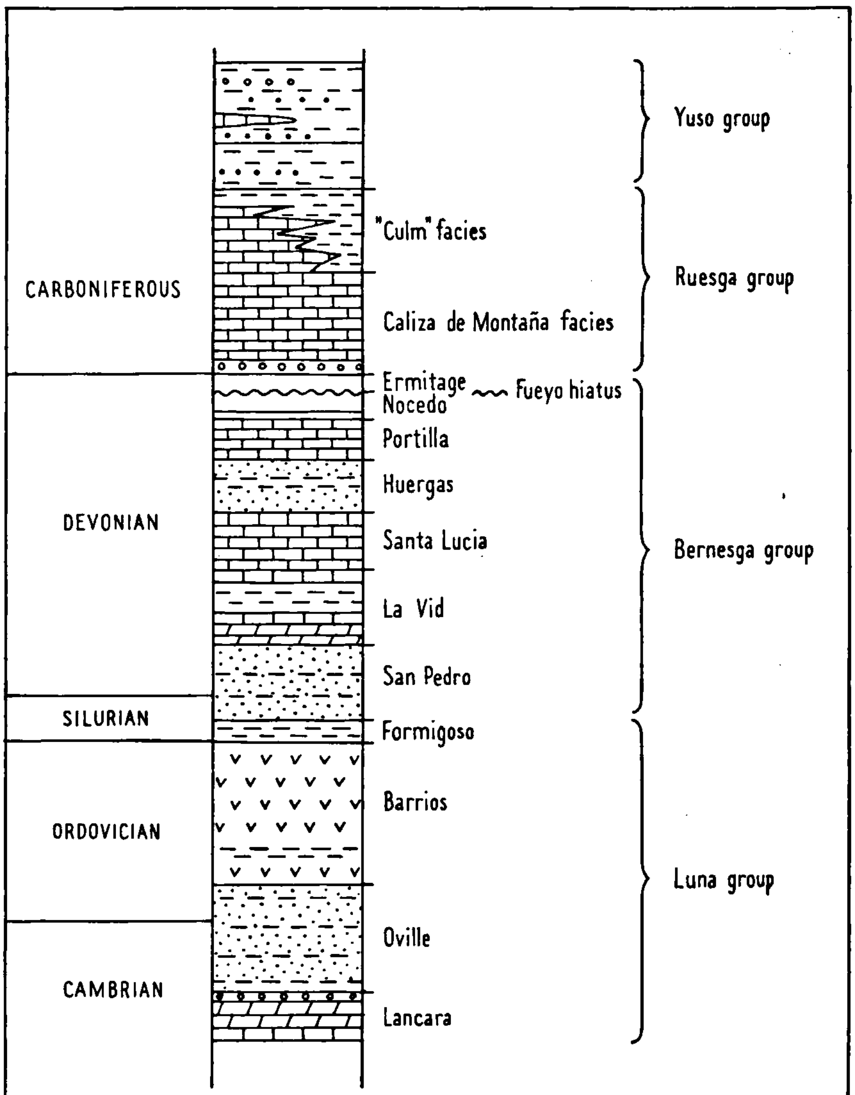


Fig. 2. The stratigraphy of the Older Palaeozoic (schematic).

The following formations lie in a conformable sequence up to the upper Devonian Ermitage formation which latter has been proved to overlap onto various older formations (Comte, 1959; Rupke, 1965).

### *Luna group*

*Lancara formation (Cambrian)*

The oldest rock in contact with strata of the Cea formation in the studied area belongs to the Lancara formation, which consists of up to 75 m dolomite and limestone overlain by 10 to 25 m of a mostly red, detrital fossiliferous "griotte"-limestone. The Lancara is unconformably overlain by the Cea formation in three places along the northern boundary of the Sabero basin and in an isolated outcrop north of Ferreras de la Puerta, in the Valderrueda basin.

*Oville formation (Cambrian — Ordovician)*

The Oville is a formation of shales, sandstones and quartzitic sandstones which overlie the Lancara griotte. Indications of volcanic activity are found in this formation: tuffs and intrusions. The thickness of the Oville varies between 180 and 260 m. The lower part of it belongs to the Upper Cambrian, while the upper part has been dated as Lower Ordovician. Like the Lancara, the Oville is in contact with Cea rocks only in a few places along the northern boundary of the Sabero basin and in the same outcrop north of Ferreras.

*Barrios formation (Ordovician)*

The next younger formation consists of massive, mostly white quartzites with some micaceous shale intercalations at the base. Its total thickness varies between 260 and 500 m. The contact between the Oville and the Barrios is transitional and it is not everywhere possible to exactly pinpoint it in the field. The Barrios occurs on or near the boundary of the Cea formation north of the Sabero basin; also north of the Tejerina syncline, and in the above-mentioned isolated outcrop north of Ferreras.

*Formigoso formation (Silurian)*

The Barrios is normally overlain by some 60 to 180 m dark grey to black or brown shales with graptolite remnants, which are called the Formigoso formation. Its fossil content indicates a Silurian age for this formation. The Formigoso can be seen unconformably overlain by the Cea formation in a few places along the northern boundary of the Sabero basin.

*San Pedro formation (Silurian — Devonian)*

The San Pedro consists of 130 to 230 m of sandstones, which contain a few conglomeratic beds or lenses, quartzitic sandstones, iron sandstones and shales. These rocks range in age from Upper Silurian to Lower Devonian. White pellet-shaped, probably tuffaceous inclusions, indicate the possibility that contemporaneous volcanic activity took place. Like the previously mentioned formations the San Pedro may be seen unconformably overlain by Cea sediments in several places along the northern boundary of the Sabero basin. Northwest of the Tejerina syncline the San Pedro crops out close to the Cea conglomerates but does not come into contact with them.

*Bernesga group*

*La Vid formation (Siegenian — Emsian)*

The La Vid formation is mostly calcareous or dolomitic in its lower part and predominantly shaly in its upper part. It contains a rich marine fauna and its total thickness varies from 35 to 245 m. The limestones occurring in the top part of the La Vid are more detrital and reddish in colour, in which they resemble the lower part of the overlying Santa Lucia limestone formation. Outcrops of the contact between the La Vid and the unconformable Cea sediments are found in a few places along the northern boundary of the Sabero basin and the western boundary of the Valderrueda basin, west of Ferreras de la Puerta.

*Santa Lucia formation (Emsian)*

The Santa Lucia is built up entirely of massive to stratified limestones, which are relatively poor in fossil content. Its total thickness ranges from 200 to 290 m. As has been mentioned before, the lower few metres of the Santa Lucia resemble the uppermost part of the La Vid, being more detrital and reddish in colour. The Santa Lucia is found in contact with the Cea formation in many places along the northern and southern boundaries of the Sabero and Ocejo basins; also between the Cea and Ocejo basins, in the immediate surroundings of the village of Ocejo and between Ocejo and Remolina, and probably in an isolated outcrop west of La Red.

*Huergas formation (Eifelian — Givetian)*

Upwards the Santa Lucia limestones are succeeded abruptly by 180 to 240 m brown shales and sandstones which together are called the Huergas formation. Its general marine character and its Devonian fossil content make it possible to distinguish the Huergas from the Cea shales. The few marine intercalations in the Cea are very restricted in thickness and usually plant remains are found close to them in the sequence. The Huergas can be seen unconformably overlain by Cea sediments along the northern boundary of the Sabero and Ocejo basins; it is in fault contact with them along the southern boundary of those basins. Outcrops of the unconformity between the Huergas and the Cea also occur in the Ocejo basin, near the village of Ocejo and south of Remolina; and in the southwestern corner of the Valderrueda basin, west and northwest of Robledo.

*Portilla formation (Givetian — Frasnian)*

The Huergas is overlain by a formation of 100 to 200 m of a bright coloured limestone with a few shale bands, which is known as the Portilla formation. The limestones yield a rich marine shelly fauna. The Portilla occurs on or near the Cea contact along the northern and southern boundaries of the Sabero and Ocejo basins; in the vicinity of Ocejo de la Peña; south of Remolina and west and northwest of Robledo.

*Nocedo formation (Frasnian)*

Upon the Portilla limestone follows the Nocedo formation, a sequence of sandstones, quartzitic sandstones and shales with in a few places some limestone intercalations called the Crémenes limestones (Rupke, 1965). In places the Nocedo contains some bands of micro-conglomerate with ferruginous sandstone pebbles. The thickness of the Nocedo varies between 50 and 250 m. It is found in contact with or near the Cea formation along the northern and southern boundaries of the Sabero and Ocejo basins; near Ocejo; south of Remolina and west of Robledo.

*Ermitage formation (Famennian — Strunian)*

The youngest Devonian formation in the studied area consists of 5 to 80 m of quartzite overlain by a band of a few metres thickness of a porous, in many places cavernous and ferruginous sandstone with many brachiopod casts. In some places, instead of this cavernous sandstone, the quartzites are overlain by 5 to 10 m of an arenaceous limestone occasionally showing current bedding.

In the Bernesga area a shale sequence called the Fueyo formation occurs between the Nocedo and the Ermitage. Further to the north and east these shales apparently have been eroded away, and the corresponding stratigraphic hiatus is called the Fueyo hiatus. The map shows that the Fueyo hiatus is in fact an angular unconformity, even though the angle of discordance is so small that the angularity is not apparent in a single outcrop. The Ermitage beds progressively overlap older rocks towards the north, showing that the erosion during Fueyo times cut down deepest in the north of our southern Cantabrian region. There the Upper Devonian Ermitage formation has been found to rest immediately on Ordovician Barrios quartzites in many places.

*Carboniferous*

The system which will be followed for the classification of the Carboniferous rocks in and around the studied area is in general that of Koopmans (1962). Koopmans distinguishes three stratigraphic groups of Carboniferous age. They are:

3. Cea formation (= Cea group in Koopmans, 1962)
2. Yuso group
1. Ruesga group

In the Ruesga group three formations can be recognised in the studied area, a very consistent band of a nodular "griotte" limestone (Sella formation, Brouwer & van Ginkel, 1964) of a few metres thickness, a Caliza de Montaña (Mountain Limestone) formation (Escapa formation, ibid.) of several hundreds metres thickness, and a "Culm" shale formation (San Emiliano, Prioro or Cervera formations, Brouwer & v. Ginkel, 1964). The black shales which occur under the griotte in other parts of the Cantabrian region, and which are reportedly of Tournaisian age (Higgings et al., 1964), are absent in the area considered in this paper. The above-mentioned formations of the Ruesga group range in age from Visean to Namurian. For more extensive information on the Carboniferous stratigraphy in the Cantabrian region reference is made to Brouwer & van Ginkel (1964) and van Ginkel (1965).

The Yuso group generally consists of a quartzite conglomerate formation and a shale formation with limestone intercalations, all of Westphalian age. A full description of the Yuso group is expected to be given in due time by Mr. J. F. Savage, M. Sc.

The Cea formation, being the main subject of this thesis, will be treated in a separate chapter.

In the considered area the Carboniferous sequence starts with a "griotte" limestone which is well known throughout the Cantabrian region. It is a pink to wine-red nodular limestone of up to 20 m thickness. The griotte is remarkably consistent in a lateral sense and forms an excellent marker horizon in the field. To the west the griotte is underlain by some black shales which are reported to be of Tournaisian age (for references see Rupke, 1965).

On the griotte follows a thick sequence of ridge-forming limestones, generally known as the Caliza de Montaña. At the base these limestones frequently show more pronounced stratification, a dark grey to black colour, and a more detrital and, in places, bituminous character.

The upper (and greater) part of the Caliza de Montaña consists of bright grey stratified to massive limestone, which is practically void of determinable organic remnants. The total thickness of the Caliza de Montaña ranges from 200 to 700 m.

The Caliza de Montaña is gradually succeeded by a paralic sequence which has been informally called the "Culm" formation (or facies). The transition from limestone to shale facies takes place in a vertical as well as in a lateral sense, so that an upper part of the Caliza de Montaña may be equivalent in age to a lower part of the "Culm". The "Culm" may even entirely replace the limestone.

The "Culm" is a sequence of probably several hundreds of metres thickness of shales, mudstones and sandstones with intercalations of quartzite conglomerate and, at the base, some stratified limestone.

Goniatites found in the griotte indicate an upper Visean to lower Namurian age for this formation (Wagner, 1957). The superposed Caliza de Montaña is probably entirely of Namurian age, at least in the vicinity of the considered area.

In the "Culm" some foraminifera were found by Mr. Savage, M. Sc., which indicate a Profusulinella B stage (van Ginkel, pers. comm., Brouwer & van Ginkel, 1964).

In principle the Yuso group can be divided into two formations: the Curavacas conglomerate formation (Kanis, 1956) and the Yuso shale formation.

No clear definition of the Yuso group has been given as yet, nor is it the present author's intention to do so. Kanis (1956, p. 405—406) described the lower part of it and named it the Curavacas conglomerate. Koopmans (1962, p. 160—162) gives a description of the Yuso (mostly the upper shale formation) as it occurs in his area. However, to give a precise definition of the Yuso group it would be necessary to study a much larger area. Such a study, being done by Mr. Savage, M. Sc., is still in progress at the present.

The description of the Yuso group given in the following lines will be restricted to the broadest generalities and will only be somewhat more detailed for the Yuso outcrops occurring in the immediate surroundings of the area underlain by Cea rocks.

The Curavacas conglomerate has its greatest development in the source area of the Carrión river, where it is reportedly over 500 m thick (Kanis, 1956). Towards the west it thins gradually and it splits up and interfingers with the Yuso shale formation. This indicates that the Curavacas conglomerate is equivalent in age to at least a lower part of the Yuso shale formation.

The Yuso group seems to be entirely of Westphalian age. From the base of the Curavacas conglomerate in the source area of the Carrión river a Westphalian A flora is known (Stockmans, in press). Wagner (1960) reports the occurrence of Westphalian B—C plants in the Curavacas conglomerate near Polentinos.

Near the summit of the Coriscao mountain, on the main divide of the Cantabrian mountain range, a flora was collected indicating a Westphalian D or possible Stephanian A age for the rocks of the Yuso shale formation, which contain them. This flora still constitutes a biostratigraphic problem, as the limestones which apparently overlie these shales have yielded Foraminifera which are probably somewhat older (Brouwer and van Ginkel, 1964, van Ginkel, in press). The Foraminifera found in the Yuso limestones in the Tejerina syncline (Mesao limestone, van Ginkel, 1965) all belong in the upper part of van Ginkel's (1959) Fusulinella A zone, which more or less corresponds with a Westphalian B—C age. In the lower part of section A in figure 3 a single leaf of cf *Linopteris obliqua* (determination by Mr. van Amerom) was found, a species which had its maximum development in the upper half of the Westphalian, and thus coincides well with the Foraminifera in the same sequence. Plants have also been found in the Yuso shale formation by Wagner (1962b) and Mr. J. F. Savage (pers. comm.).

The Yuso group is considered as an equivalent of the Central Asturian Upper Carboniferous (Llopis Llado, 1955). However, no coal of any economic importance has ever been found in this eastern extension of the Asturian basin, whereas a great part of Spain's yearly coal output comes from the main Central Asturian basin.

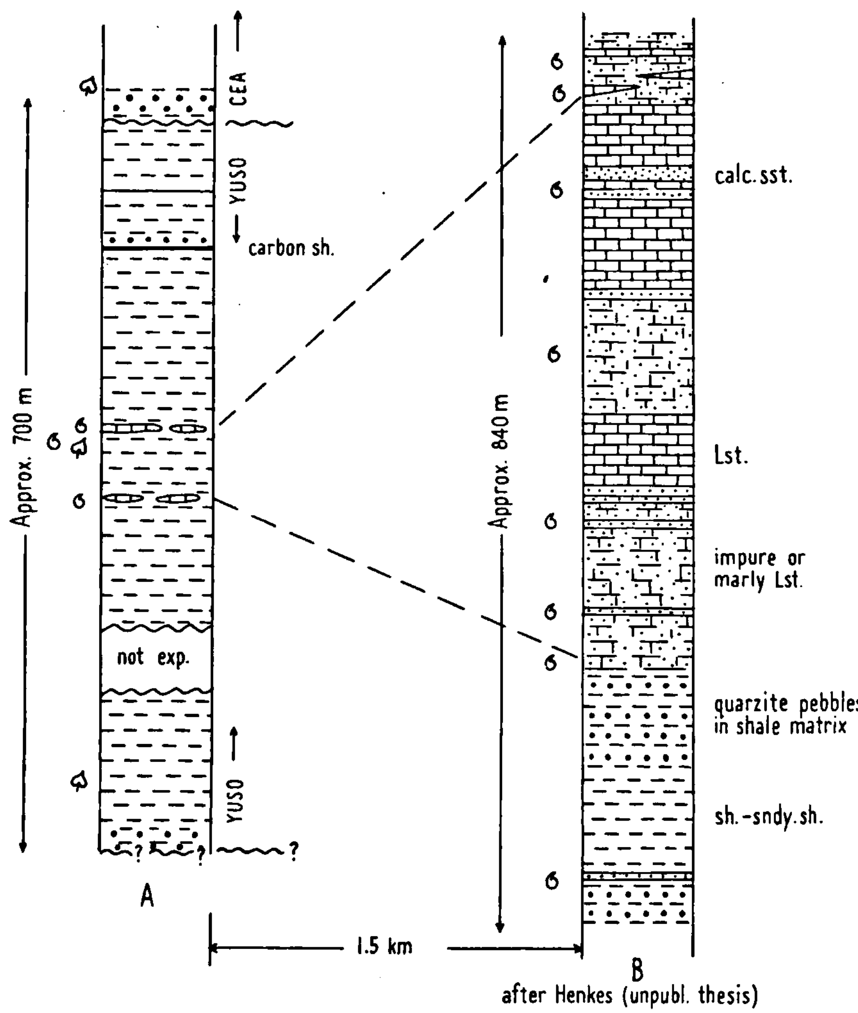


Fig. 3. Two sections of the Yuso in the south flank of the Tejerina syncline due north of Prioro.

## CEA FORMATION

### *Introduction*

The stratigraphic unit called the Cea formation forms the main topic of the present paper. Koopmans (1962) was the first author to use the name "Cea group" in a publication. The term had been in use for some time with the geologists of the Leiden University to indicate the unconformable coal-bearing sequence of upper Westphalian D or Stephanian age in the area between the Carrión and the Porma rivers. These rocks have their widest extension in the upper Cea river-basin, hence the classification "Cea group". However, the Cea unit is too monotonous to justify the term "group" for it, and in this paper the Cea sequence will be classified as a "formation" (see Am. Comm. on Strat. Nom., 1961).

The sediments comprised in the Cea formation are, in order of quantitative importance, shales, sandstones, conglomerates and coal seams. In four places in the Valderrueda basin marine fossils were found in shale or sandstone beds of 0,5 to 2 m thick. By definition the Cea formation should actually be called a paralic sequence. However, it should be kept in mind that the marine intercalations represent no more than a fraction of 1 % of the total thickness, and that the vast bulk of the Cea formation is of purely limnic origin. More to the east, in the Guardo-Cervera coal basin, the Cea deposits clearly show an increase of marine intercalations towards the east or southeast (Kanis, 1955; Koopmans, 1962), culminating in the Stephanian of the Pisuerga basin, where limnic beds alternate with marine limestones containing Foraminifera and other marine fossils (Nederlof, 1959; van Ginkel, 1959, 1965). Conversely it can be said that the Cea formation becomes gradually more limnic towards the west. This tendency is recognizable even within the more restricted area discussed in this paper. Whereas some marine influence was observed in the Valderrueda basin, no trace of it shows in the Ocejo and Sabero basins. The Tejerina basin, more to the north, also seems to be of purely limnic origin. Obviously a lateral transition from a paralic to a limnic facies exists in the studied area.

The basal beds of the Cea formation vary in lithology from place to place. They may be either shale with coal intercalations, quartzite conglomerate, quartzitic sandstone to quartzite, or limestone conglomerate. With the designation "quartzite conglomerate" is meant: a conglomerate with quartzite cobbles and pebbles alone or mixed with minor amounts of limestone pebbles. A "limestone conglomerate" is a conglomerate in which limestone pebbles predominate.

In general the Cea formation shows onlap towards the west in the studied area.

More detailed stratigraphic information will be given on the following pages, where the various basins will be described separately.

The typical cyclothem which occurs in the lower part of the Cea formation will be discussed separately.

There are relatively few places where a clear, sharp, unconformable contact between the Cea formation and the older formations can be observed. However, such outcrops do exist and will be described later in this paper. Furthermore the map clearly shows that the Cea beds generally overlie older formations that have undergone folding and erosion before the Cea formation was deposited.

### *Subdivision*

In the Valderrueda basin, which has the most complete stratigraphy of the four coal basins described in this paper, coal production appears to come from three different zones of the stratigraphic column. These productive zones differ in:

a. lithology
b. age (i.e. fossil plant associations)
c. coal composition (volatile content).

Quiring (1939) also reports the existence of three productive zones in the Guardo-Cervera coal basin. On the basis of plant determinations by Gothan, he dated the lower two of these zones as Westphalian D and the upper one as Stephanian A. Later investigations by Kanis (1956) and Koopmans (1962) have shown that at least the eastern part of the Guardo-Cervera basin is probably entirely of lower Stephanian age. In its western part, however, it seems highly probable that the lowermost strata of the coal measures are of Westphalian D age, as typical Westphalian floral elements have been found on mine tips which probably contain a mixture of the entire mineable section. This might be the explanation for the mixtures of typical Westphalian and Stephanian elements in this area.

For lists of representative assemblages of plant fossils of the Guardo-Cervera basin reference is made to Wagner (1964) and Stockmans (in press).

A threefold sub-division of the Cea formation, according to its productive zones, would seem logical from a mining point of view. However, in the field, where mapping is already difficult due to the monotonous lithology of the Cea formation, such a subdivision would be useless for mapping purposes.

In the Valderrueda basin upper Westphalian D floras, lacking any typical Stephanian elements, are found near the base of the coal measures. These basal Westphalian sediments may be up to 1200 m thick in the eastern parts, along the Rio Carrión, but very thin or even nonexistent along the western edges of the basin. They consist of shales and sandstones with coal seams and either quartzite conglomerate bands or a band of quartzitic sandstone to quartzite. Nowhere do they contain any limestone conglomerate, with a few almost negligible exceptions in the Valderrueda and Tejerina basins. Where limestone conglomerate is found directly overlying Older Palaeozoic rocks it is due to onlap of the limestone conglomerates onto an old topographic high where the basal sequence was not deposited.

Upwards in the section the Westphalian D coal measures and quartzite conglomerates are followed by a series of shales and sandstones with coal seams, with frequent intercalations of limestone conglomerate in its lower part and without any pure quartzite conglomerate. The fossil plant associations found in this part of the sequence invariably show Stephanian characteristics. Thus, in fact, two cycles can be recognized in the Cea formation: a Westphalian lower cycle with quartzite conglomerates at its base and no limestone conglomerates, and a Stephanian upper cycle with limestone conglomerates in its lower part and void of quartzite conglomerate. Geologically this twofold subdivision is the most logical one for two main reasons:

1. the palaeobotanical and lithological boundaries coincide and
2. the lithological boundary separates good mappable units, which cannot be said of the threefold subdivision according to productive zones.

In comparison to the Stephanian type section it could be remarked that the lowermost limestone conglomerate of the Cea formation is in approximately the same stratigraphic position as the Holz conglomerate in the Saar-Lotharingen area (Corsin, 1952; Bode, 1960).

In the Tejerina and Ocejo coal basins this twofold subdivision of the Cea formation is equally applicable, albeit that in the latter basin the lower Cea subdivision is reduced to a few tens of metres or even to zero. This, however, illustrates all the better the general onlapping character of the Cea formation towards the west and northwest. On the ground of the above mentioned data the choice of the described subdivision of the Cea formation into two members seems justified. The type-section for the lower member lies on the western bank of the Carrión river, between Guardo and Velilla del Río Carrión. It is therefore called the Carrión member. The upper member cannot be represented by one type-section. The lateral variations are so rapid and frequent that great differences exist between separate sections. The section which was arbitrarily chosen to represent the upper Cea member, lies within the concessions of the Hulleras de Prado, S.A., and this unit is therefore called the Prado member. Actually the Prado section only represents the lower part of the Prado member. The upper part is represented by the Sabero section. The following terminology is proposed:

Cea formation { Prado member
Carrión member

The lower limit of the Cea formation is determined by the unconformity which separates this sequence from the older rocks. In the Pisuerga basin where the Upper Carboniferous sequence is almost complete from lower Westphalian to Stephanian, the lower boundary of the Cea formation is determined by the San Cristobal disconformity (de Sitter, 1955; Wagner & Breimer, 1958). An upper limit for the Cea formation would be difficult to establish. Normally it is there where the typical facies of this unit ceases, which more or less happens to coincide with the upper limit of the Carboniferous system in the Cantabrian region.

At its type locality, along the Carrión river, the Carrión member attains a maximum thickness of about 1200 m, mostly of shale and sandstone with anthracite seams, bu: it thins rapidly to the west. In the western part of the Sabero basin and in more westerly basins no trace of this unit is found.

In the Tejerina basin the Carrión member consists mostly of quartzite conglomerates with some lenses of limestone conglomerate and shale intercalations.

The Prado member is meant to represent the entire Stephanian sequence present in these productive basins as a whole. But in its type locality the Prado member contains only lower Stephanian A rocks, while in the Sabero basin higher Stephanian A and possibly Stephanian B sediments are present. The Stephanian part of the Tejerina section is roughly equivalent in age to the Prado section, but the Sabero section is in part younger. The still more westerly basins, Matallana, Villablino, Tineo etc. even reach higher into the Stephanian sequence. Those younger parts of the Stephanian section may be simply referred to as "Cea formation" as there the Carrión member is absent. The composite Cea type section is schematically represented in fig. 4.

The maximum total thickness for the compiled Cea formation would then be about 1200 m for the Carrion member and some 1500 to 2500 m for the Prado member, together about 2700 to 3700 m. However, these composite maximum thicknesses do not occur in any single locality.

For practical purposes the section between and including the two lower limestone conglomerates of the Prado member has been selected to serve as a stratigraphic marker. It is referred to as "Villacorta beds" and has been given a different shade on the map. The separation of the Villacorta beds as an informal stratigraphic marker has no further stratigraphic implications.

Later in this paper each of the four studied basins will be treated separately, and detailed local sections will be presented.

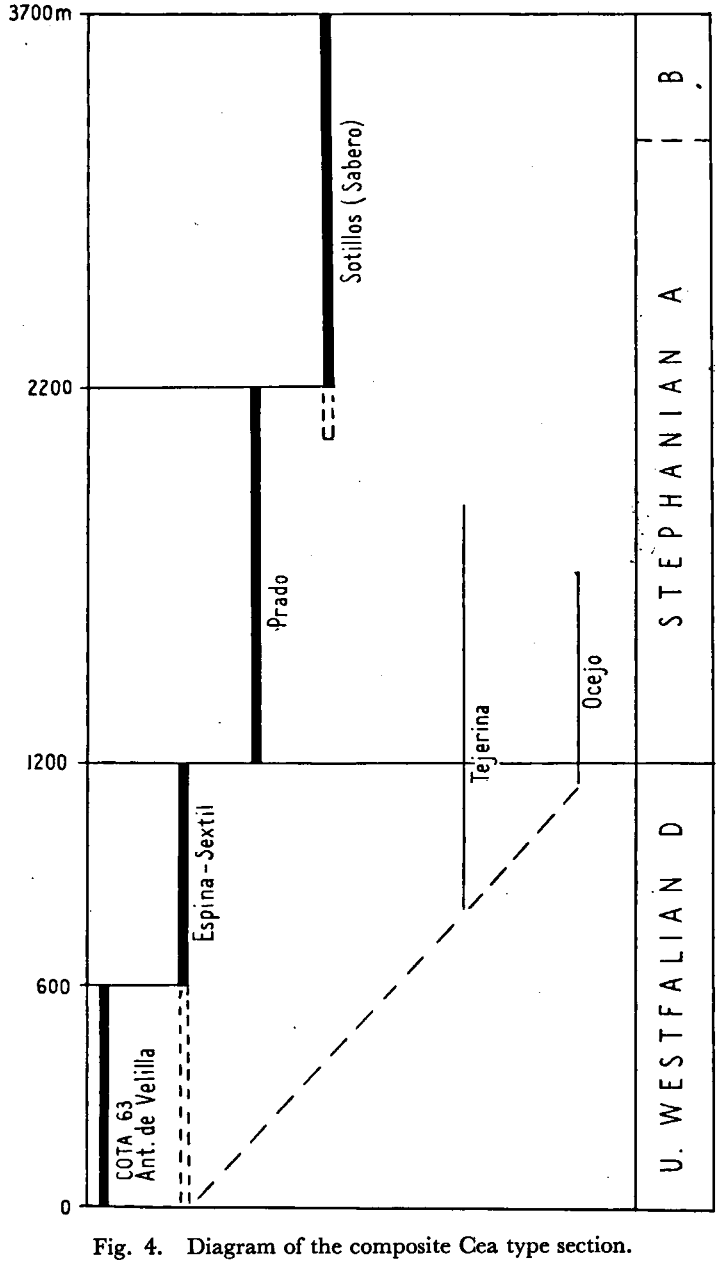


Fig. 4. Diagram of the composite Cea type section.

*The typical cyclothem*

The typical cyclothem observed in the Cea formation in the considered area consists of the following sequence:

1. underclay
6. shale
5. sandy shale
4. sandstone
3. shale
2. coal
1. underclay

This is the ideal cyclothem, but usually not all the units are present.

The cyclothems are best developed in the Carrión member of the Cea formation. In the Prado member they are more irregular and less conspicuous.

As an example of the cyclic development of the Carrión member a section is shown in fig. 5 which has been measured in the cross-cut Cota 219 of Antracitas de Velilla, S.A. Here ten cyclothems are recognized in a sequence of 65 m thickness. It is obvious that the ideal cyclothem in the Carrión member has the form as is re-

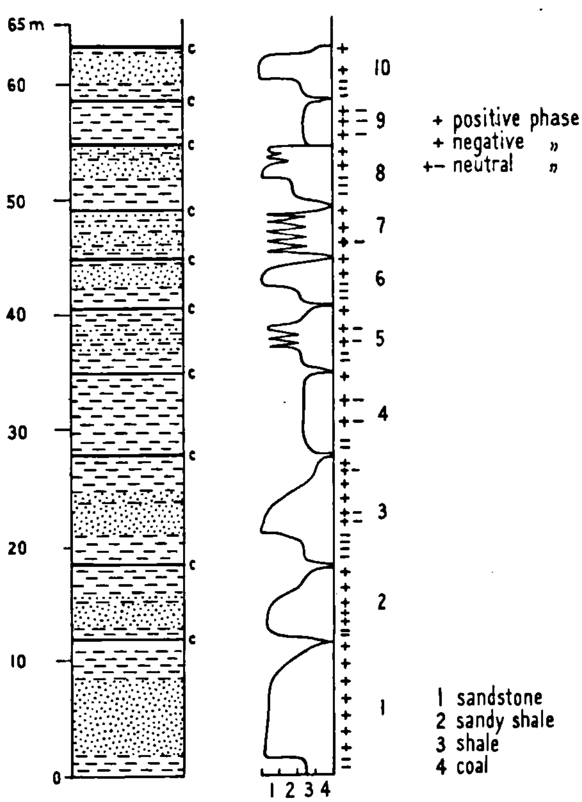


Fig. 5. Cyclothems in the cross-cut Cota 219 of Antracitas de Velilla, S.A.

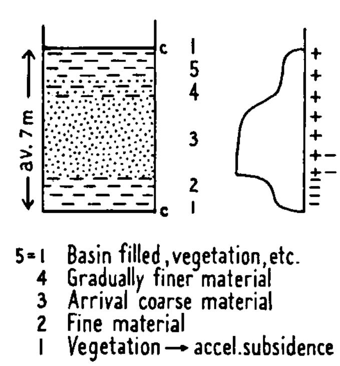


Fig. 6. The ideal typical cyclothem of the Cea formation.

presented in fig. 6. As the underclay has not been specifically indicated this ideal typical cyclothem consists of 1. coal, 2. shale, 3. sandstone, 4. sandy shale and 5. shale.

As the Cea formation is shown to have been deposited in basins subsiding between east-west faults, the author feels that the cyclic development of this formation must be primarily explained by a rhythmic nature of the subsidence. Whether this rhythmic subsidence must be taken as an alternation of periods of stability and periods of subsidence, or as a continuous movement on which a rhythmic pattern of accelerations is superposed, is not immediately relevant. Personally the author is inclined to believe the second possibility as it fits the idea that the subsidence of the Cea basins along faults is a (intermittent) structural adjustment to the (continuous) general tilt occurring during Cea deposition. The following interpretation of the typical cyclothem in the Carrión member is based on this concept.

*1. Coal*

It is generally accepted that a coal bed represents a period of relative stability which is considered here to have been slow subsidence. The continuing slow subsidence was compensated by the vegetational deposition.

This period of relative stability was followed by a sudden acceleration of the rate of subsidence, which initiated the formation of all the following units of the cyclothem.

First the surface was covered by a layer of water too deep to permit further vegetational life. The vegetation died and was deposited on the bottom protected from oxidation by the covering water and mud.

*2. Shale*

The accelerated subsidence caused a rejuvenation of the relief in the source area of clastic sediment. An amount of clastic material was released which was proportional to the amount of subsidence. The fine grained fraction would travel faster than the coarse grained one and would arrive in the depositional area earlier. A layer of fine mud was spread out over the dead vegetation lying in the basin, thus forming what is now known as roof shales. This unit formed the beginning of a negative phase of deposition.

*3. Sandstone*

After some time the coarser fractions started to arrive. They may have become mixed with certain amounts of fine material, in which case the boundary between units 2 and 3 will be transitional; or rather well sorted, then a sharp boundary (or diastem) may occur. Towards the end of unit 3 a positive phase of deposition set in.

*4. Sandy shale*

When the rejuvenated relief became leveled, the supply of coarse material diminished and the relative amount of fine material rose. Thus there is a gradual transition to unit 5.

*5. Shale*

In this last stage of the cyclothem the supply of clastic material diminished. At the same time the subsidence of the basin had been almost completely compensated by the subsequent sedimentation and the basin filled up to a level where it was possible again for vegetation to reappear.

Of course, all sorts of variations on this ideal process are possible and, accordingly, all sorts of variations are seen in the cyclothems. However, a description of the several varieties of cyclothems in the studied area does not lie in the scope of the present paper.

*Relation of the Cea cyclothem to the tectonic environment*

Much has been written on the possible causes for the formation of Carboniferous cyclothems (see reviews in Goodlet, 1959; Jessen, 1961).

Theories involving diastrophic control (Rutten, 1952; Weller 1956, and many others), eustatic changes of sea level (Wanless & Shepard, 1936; Wheeler & Murray, 1957), or even a purely physical theory of self-maintained oscillations of relaxation (Delmer, 1952) have been propagated.

It is the author's opinion that, in the case of the Cea cyclothem, a theory of diastrophic control as has been suggested by MacGregor & Manson or Richey (in Goodlet, 1959) gives the best explanation for its formation. This theory generally involves an alternation of (short) periods of rapid and (long) periods of slow subsidence.

Later in this paper (p. 140) it will be shown that the palaeogeographic picture of the Cea formation in the studied area leads to the conclusion that the movement of subsidence during its deposition can be split into two components. These are:

1. a continuous, relatively slow subsidence because of regional tilt to the southeast and
2. spasmodic subsidence of the basin along bordering fundamental faults, probably as a structural adjustment.

Thus the positive phase of the Cea cyclothem, i.e. the upper part of unit 3 and the subsequent units 4 and 5 (and 1 of the next cyclothem) could be related to the regional tilt. The negative phase then coincides with the spasmodic movements along the faults bordering the basin of deposition.

## *The Valderrueda basin*

*The unconformable contact*

Outcrops in which the actual angular unconformable contact between the Cea formation and the older rocks can be clearly observed are not known from the Valderrueda basin. However, in the field and on the map there is unmistakable evidence that this type of contact exists, and there is no doubt that the pre-Cea rocks were folded and eroded before the Cea was deposited. A few exposures of the unconformity will be described in the following.

North and west of La Red upper Cea limestone conglomerates (Stephanian A) are in obvious sedimentary contact with respectively Caliza de Montaña (Visean-Namurian) and probable Santa Lucia limestone (middle Devonian).

Along the path from Prioro to La Red, about 1 km west of the Cea river, a good exposure of the unconformable contact between the Las Conjas quartzite conglomerate and limestone conglomerates of Yuso age can be observed. A vertical quartzite congomerate bed (Carrión) of a few metres thickness cuts off two subvertical limestone conglomerate beds (Yuso) of about 1 m thick each (fig. 7) with an angle of approximately 20°.

On the divide between the Carrión and the Cea rivers, 3.5 km southwest of Velilla del rio Carrión (in a place called Sextíl by local inhabitants) Carrión quartzite conglomerate bands (Westphalian D) curve around a spur of Devonian quartzite to form an anticline.

On the western bank of the Carrión a few Caliza de Montaña inliers are exposed, surrounded by Cea sediments. They probably represent relics of the pre-Cea relief, now bared by recent erosion. They are rimmed by some 10 to 100 cm of a gravel-sized limestone conglomerate with a shale matrix.

Along the northern boundary of the Devonian quartzites of Sextíl, and approximately 800 m west of the Carrión river, red shales and sandstones (20—40 m thick) containing some plant remains (Calamites sp., Cordaites sp.) overlie the Devonian and Lower Carboniferous rocks. Their red colour is most probably due to previous or contemporaneous weathering of the underlying Caliza de Montaña limestone.

Further to the east, in the Pisuerga basin, the sediments comparable to the Cea formation lie in a relatively continuous stratigraphic succession from lower Westphalian to Stephanian A age (de Sitter, 1955; Nederlof & de Sitter, 1957; Nederlof 1959). Only a local disconformity, observed on the San Cristóbal and Cabra Mocha mountains (Wagner & Breimer, 1958) betrays a break in the stratigraphic record in a place (or rather at a time) which is roughly correlatable with the base of the Cea formation in the studied area.

Fig. 7. Unconformity between Carrión quartzite conglomerates (left) and Yuso limestone conglomerates (photo by H. Henkes).

*Subdivision*

The first sediments of the Cea formation in the Valderrueda basin vary lithologically from place to place. Along the eastern boundary of the basin, on the right bank of the Carrión river, they are predominantly shales with, in some places, some poorly rounded limestone gravel at its very base. The underlying rocks are mostly Caliza de Montaña, but in a few places Devonian quartzites are exposed, mainly in the cores of pre-Cea anticlinal structures.

In the Sextíl area, where an anticlinal nose of Devonian quartzite plunges to the west to disappear under the Cea sediments, the latter consist of two quartzite conglomerate bands of some 10 to 20 m thickness. The conglomerates are not in direct contact with the quartzite, but are preceded by a few tens of metres of shale and sandstone in which a few fragments of marine organisms were found. Only one shell could be determined by Dr. A. Breimer as *Meekella* sp., an Upper Carboniferous brachiopod. The two quartzite conglomerate bands will be referred to as the Sextíl conglomerates in the following text.

In the northern part of the Valderrueda basin, between Morgovejo and Prioro, the basal sediments of the Cea formation consist of several quartzite conglomerate beds varying in thickness from 10 to 30 m. The space between the conglomerates is occupied by dark grey to black shales with some sandstone.

The total length of the north-south section through the Las Conjas canyon is more than 1500 m, but the true thickness of the basal succession there is about 650 m, its lower 500 m mostly consisting of quartzite conglomerate (section $c_N$—$c_S$). The exaggerated thickness observed at first sight is a result of the rather intricate folding of these rocks (fig. 7). The conglomerate beds are best developed and contain less intercalated shale in the Cueto mountain, south-east of Prioro where they seem to reach a thickness of some 700 m. They wedge out completely to the south within a distance of 1 to 2 km, and to the west before they reach the village of La Red. The quartzite conglomerates of the La Red syncline which overlie Caliza de Montaña in an outcrop north of La Red, are stratigraphic equivalents of the Las Conjas conglomerates and have undoubtedly been originally connected with them.

The shale intercalations of the Las Conjas conglomerates have not yielded any plant or other fossils.

In or just above the hitherto described basal sediments, floras have been found in which no typical Stephanian elements occur. The plant assemblages indicate unequivocally that these rocks and the underlying basal beds were formed during upper Westphalian times. The basal deposits are overlain by shales, sandstones and anthracite beds, which reach a thickness of up to 1200 m. In contrast to stratigraphically higher parts of the Cea formation, these Westphalian deposits do not contain any typical limestone conglomerates. A few exceptions to this rule occur in some places and will be described in detail later (p. 99).

All these sediments are included in the Carrión member of which a more extensive description will be given on p. 97.

North of La Red and all along the western border of the Valderrueda basin down to Prado de la Guzpeña, the basal beds of the Cea formation consist of rocks belonging to the Prado member, mostly shales and sandstones with limestone conglomerate beds of 1 to 20 m thick. Whereas the limestone conglomerates lie almost immediately upon pre-Cea rocks in the western part of the basin, they conformably succeed an ever-thicker section of the Westphalian Carrión member towards the east. This is illustrated by the east-west section on Appendix III.

Floras from several horizons between the limestone conglomerates indicate ages ranging from lowermost to middle Stephanian. The limestone conglomerates and accompanying rocks are included in the Prado member.

To summarize, it can be said that the Cea formation has been subdivided into two parts:

1. a Carrión member of Westphalian D age, with quartzite conglomerates, no limestone conglomerates, and anthracitic coal (maximum thickness 1200 m);

2. a Prado member characterised by floras of Stephanian age, the frequent occurrence of limestone conglomerates and the lack of quartzite conglomerates, and dry to fat coal (maximum thickness 2500 m).

More detailed investigation may well reveal additional differences between the Carrión and Prado members. For instance, the sedimentary cycles seem to be more regular and therefore easier to recognize in the Carrión member than in the Prado member. In the following the characteristics of the two subdivisions of the Cea formation will be given a more detailed treatment.

*The Carrión member.* — Due to the lateral changes in lithology the stratigraphy of the Carrión member cannot be represented in a single stratigraphic column. Therefore three sections of this formation will be given. For the location of the sections the reader is referred to the index map on Appendix III.

The first one, section $a_N$—$a_S$, lies between the Devonian quartzite of the Sextíl and La Espina. This section is mainly intended to represent the lower part of the Carrión member in that part of the area. The thickness of the upper (southern) part is not reliable since it crosses at least one major fault, the northern branch of the Southern Border Fault, which may have cut away a few hundred metres of strata

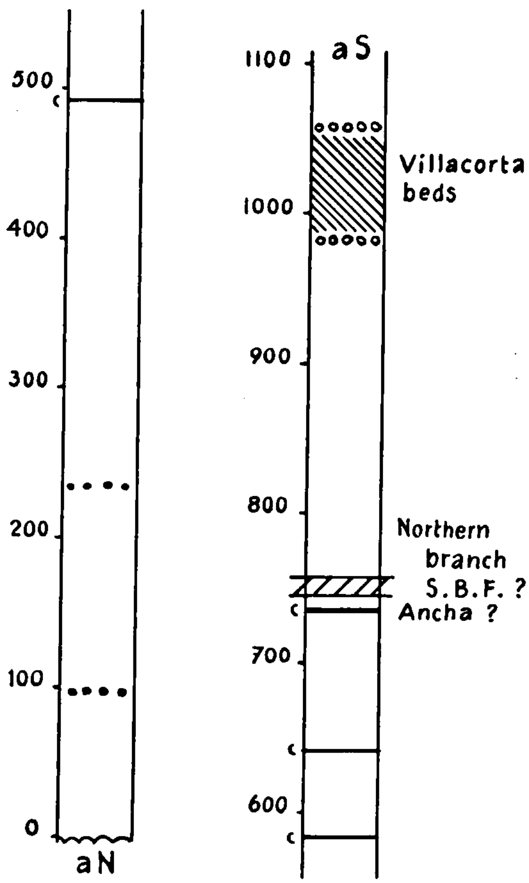


Fig. 8. Section $a_N$—$a_S$ between Sextíl and La Espina.

(fig. 8). Section $b_E$—$b_W$ undoubtedly represents the mid-basin sedimentation of the Carrión member. It is thicker, it has a higher shale content than the other sequences and it lacks any conglomerates. For the greater part this section has been measured in the general crosscut (Cota 63) of the mining company Antracitas de Velilla, S.A., the entrance of which lies about 1.7 km west of Velilla del rio Carrión. Section $b_E$—$b_W$ is considered as the principal type section for the Carrión member (fig. 9).

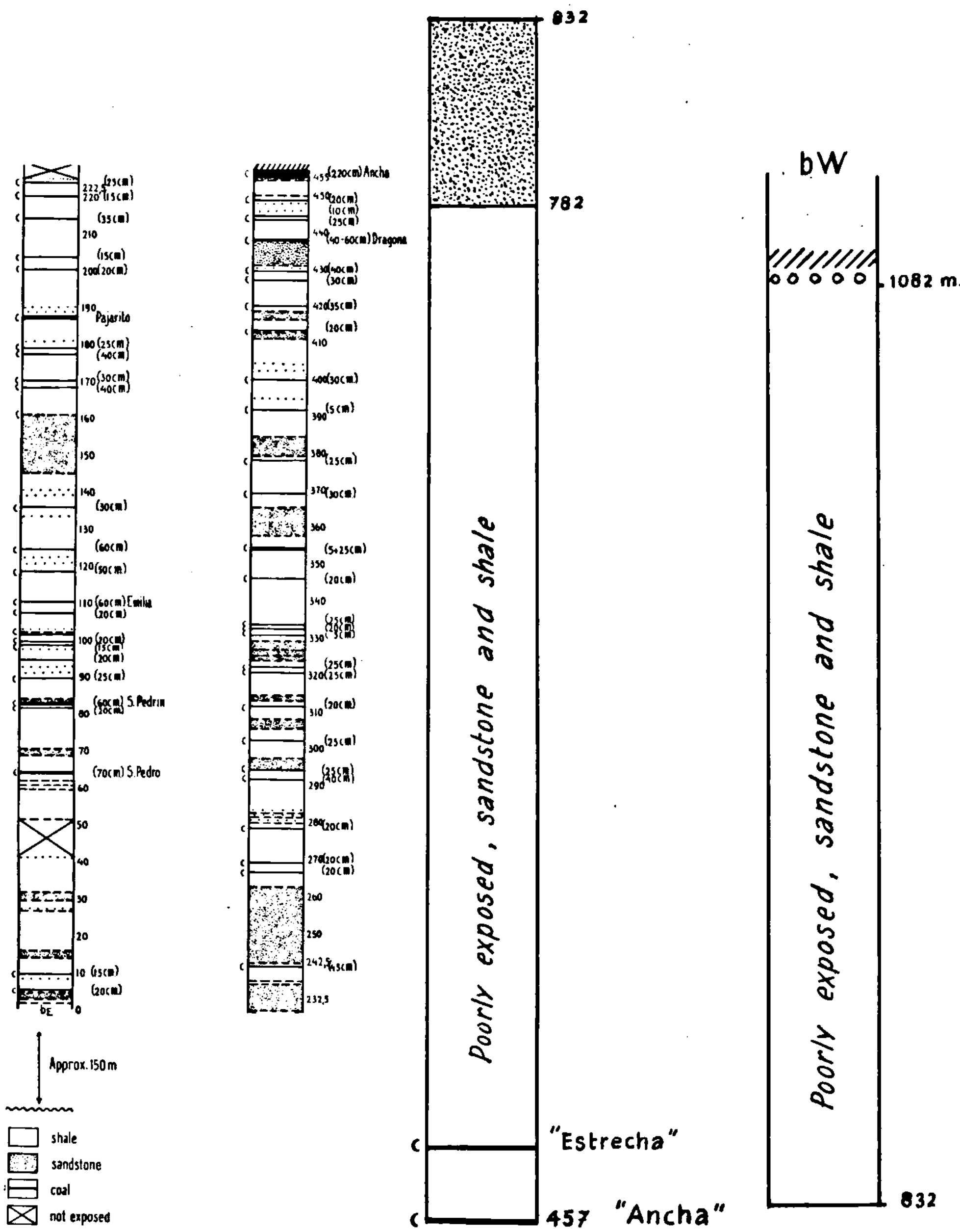


Fig. 9. Section $b_E$—$b_W$ in cross-cut Cota 63 of Antracitas de Velilla, S.A.

Section $c_N$—$c_S$ lies north of Morgovejo and crosses the Las Conjas quartzite conglomerates (fig. 10).

While it can be accepted as a rule that the Carrión member does not contain any limestone conglomerates, a few exceptions on this rule are known to exist in the studied area. One of those exceptions occurs in the Tejerina syncline and will be discussed later in this paper (p. 106). Another locality is situated a few hundreds of metres north of the quartzite conglomerates in the north flank of the Sextíl anticline. Two lenses of limestone conglomerate were observed there. Both are 1 to 1.5 m thick and a few metres long. Their existence is probably due to the same local higher relief element in the pre-Cea erosion surface which caused the formation of the quartzite conglomerates of Sextíl. The described limestone conglomerate outcrops are not shown on the map because of their small size.

North of Morgovejo, in the Balneario anticline, a few lenses of limestone conglomerate occur about 100 m above the base of the Cea formation.

Finally, north of La Red, a few bands of limestone conglomerate which are intensely folded, immediately overlie Caliza de Montaña limestone from which they are obviously derived. The limestone conglomerates are overlain by a band of Las Conjas quartzite conglomerate. All these exceptional occurrences of limestone conglomerate in the Carrión member are almost certainly due to the presence of isolated fault scarps of limestone when that unit was being deposited. In every one of the described cases the presence of limestone in combination with a fault can be demonstrated.

It has been observed in several places that, where the basal sequence is not developed as a conglomerate, its top is formed by a sandstone, which is hard, in many places quartzitic, irregularly bedded and lighter coloured than most other sandstones of the Cea formation. This sandstone horizon is considered as a finer-grained equivalent of the basal quartzite conglomerate. It was observed in the type locality of the Carrión member (section $b_E$—$b_W$) and east of La Red where a lateral transition of the Las Conjas quartzite conglomerates to such a quartzitic sandstone exists. It also occurs in the Ocejo basin.

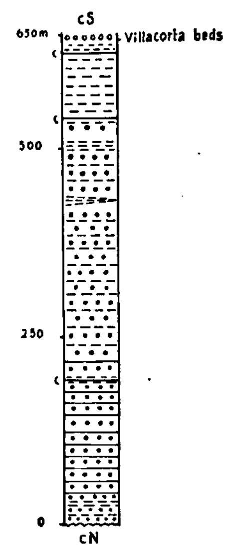

Fig. 10. Section $c_N$—$c_S$ in the Las Conjas canyon.

Palaeontology and age: From section $a_N$—$a_S$ no fossil material has been collected. However, on the north side of the Devonian quartzites of Sextíl a fossil flora was found in shales (Loc. 560) which belong somewhere within the lower 100 m of section $a_N$—$a_S$.

The following species have been identified by Mr. van Amerom:

*Mariopteris nervosa* BRONGNIART
*Sphenophyllum emarginatum* BRONGNIART forme truncatum RENAULT & ZEILLER
*Alethopteris grandini* (BRONGNIART)
*Alethopteris friedeli* P. BERTRAND
*Linopteris obliqua* BUNBURY
*Mixoneura* sp.
*Aphlebia* of *Mixoneura* sp.
*Pecopteris unita* BRONGNIART
*Pecopteris* sp.

The most likely age indicated by this plant association is upper Westphalian D (van Amerom, pers. comm.).

The tip of the cross-cut "Valdehaya" of the mining company Antracitas de Besande has yielded the following flora to Prof. Stockmans. The mined section at that locality corresponds with the lower 200 m of section $b_E$—$b_W$.

*Annularia mucronata* SCHENK
*Sphenophyllum truncatum* SCHIMPER
*Pecopteris sitteri* STOCKMANS & WILLIÈRE
*Pecopteris besandenensis* STOCKMANS & WILLIÈRE
*Pecopteris* sp.
*Alethopteris friedeli* P. BERTRAND
*Alethopteris zeilleri* WAGNER
*Alethopteris* sp.
*Callipteridium* sp.
*Mariopteris nervosa* (BRONGNIART)
*Linopteris obliqua* (BUNBURY)
*Mixoneura ovata* (HOFFMANN)
*Neuropteris scheuchzeri* (HOFFMANN)
*Sphenopteris gutbieri* GOEPPERT

As the former one, this list is also representative for the upper Westphalian D. (Stockmans, pers. comm.).

From the upper part of section $c_N$—$c_S$, in shales exposed in the entrance of an abandoned colliery (Loc. 11), the following specimens were collected (determ. Stockmans):

*Lepidostrobus* sp. (cf. *Lepidostrobus meunieri* ZEILLER)
*Lepidophyllum majus* BRONGNIART
*Lepidophyllum anthemis* (KOENIG)
*Pecopteris unita* BRONGNIART - abundant
*Alethopteris grandini* BRONGNIART
*Alethopteris lonchitifolia* P. BERTRAND
*Pecopteridium devillei* P. BERTRAND (= *Alethopteris plebeja)*
*Alethopteris friedeli* P. BERTRAND
*Mixoneura ovata* (HOFFMANN)
*Neuropteris scheuchzeri* HOFFMANN - abundant
*Linopteris obliqua* (BUNBURY) - abundant
*Sphenophyllum emarginatum* BRONGNIART - abundant
*Annularia sphenophylloides* (ZENKER)
*Annularia stellata* (SCHLOTHEIM)
*Sigillaria tessellata* BRONGNIART
*Pachytesta voidus* (ZEILLER)
*Pinnularia* sp.

Each of the plants listed above could occur in the Westphalian D as well as in the Stephanian A. The association as a whole, however, is more in its place in the upper Westphalian D than in the Stephanian, as it lacks any typical Stephanian species (Stockmans, pers. comm.).

Other plant fossils found in the Lower Cea in the Valderrueda basin are the following (collected and determined by Prof. Stockmans):

From the tip of the Estrella Azul mine near Caminayo:

*Lepidophyllum* sp. (cf. *triangulare* ZEILLER)
*Pecopteris* cf. *monyi* ZEILLER
*Pecopteris hemitelioides* BRONGNIART
*Pecopteris* sp.
*Alethopteris grandini* (BRONGNIART)
*Mixoneura ovata* (HOFFMANN)
*Neuropteris scheuchzeri* HOFFMANN
*Sphenophyllum* sp.
*Pinnularia* sp.
*Cordaites* sp.

From a mine tip situated about 700 m west of Caminayo, along the path to this village (stratigraphically some 100 to 200 m below the Las Conjas conglomerates):

*Pecopteris hemitelioides* BRONGNIART
*Pecopteris unita* BRONGNIART
*Pecopteris* sp. nov. sp. (= *miltoni* KIDSTON of Radstock)
*Alethopteris friedeli* P. BERTRAND
*Sphenophyllum emarginatum* BRONGNIART
*Annularia sphenophylloides* (ZENKER)
*Annularia stellata* (SCHLOTHEIM)
(*Anthraconaia*? aff. *pruvosti*)

From an exposure near the colliery of the Estrella Azul company near Caminayo:

*Alethopteris grandini* (BRONGNIART)
*Neuropteris scheuchzeri* HOFFMANN
*Linopteris brongniarti* (GUTBIER)
*Cordaites* sp.

These assemblages also indicate a Westphalian D rather than Stephanian age (Stockmans, pers. comm.).

From exposures north of Caminayo, as reported by Henkes (1959):

Loc. 552 (Henkes), (determ. Stockmans)

*Alethopteris grandini* BRONGNIART
*Annularia stellata* (SCHLOTHEIM)
cf. *Pecopteris hemitelioides* (ZENKER)

Loc. 559 (Henkes)

*Sphenophyllum emarginatum* BRONGNIART
*Annularia stellata* (SCHLOTHEIM)
*Pecopteris hemitelioides* (ZENKER)
*Pecopteris unita* BRONGNIART
*Alethopteris ambigua* LESQUEREUX (determ. Wagner)
*Alethopteris* sp.
*Pecopteris* sp.
(*Anthraconaia* sp.)

All the above mentioned plants could occur in the Stephanian A, but the absence of typical Stephanian elements and the occurence of *Alethopteris ambigua* (LESQ.) make an upper Westphalian D age more probable.

The palaeobotanic evidence cited above seems to warrant the statement that the Carrión member, that is, the part of the Cea formation in the Valderrueda basin which occurs under the lowest limestone conglomerate, is entirely of upper Westphalian D age.

Economic aspects: The Carrión is the richer coal-producing one of the two Cea members. It yields anthracitic coal ranging from 3 to 10 % in volatile matter.

Production comes mainly from 4 to 6 coal beds with an average total thickness of about 3 m. The coal reserves are estimated as follows:

Average total surface (for mining down to about 700 m above sealevel):

13 million $m^2$

Average total coal thickness:

3 m

Average specific gravity of anthracite:

1.5

Gross total tonnage:

13 million $\times$ 3 $\times$ 1.5 = 58.5 million metric tons

It is estimated that no more than 40 % of the coal will be mineable due to sedimentary and tectonic disturbances. That makes a total recoverable coal reserve of 0.4 $\times$ 58.5 million = 23.4 million metric tons. Of this amount the total production up to the present date has to be subtracted. Such information is, however, not available to the present author.

The concessions on the Carrión member are divided over at least six mining companies of some local importance. It does not lie within the scope of the present study to give reserve estimates for each of the companies separately.

*The Prado member.* — A reliable detailed stratigraphic column is as difficult to give for the Prado as for the Carrión member. Lateral changes of the sediments are quick and frequent so that the stratigraphy is different from place to place. Besides, the Prado strata are generally more strongly folded and faulted than the underlying Carrión member. Finally, no long mine sections exist in the Prado and consequently no truly continuous sections of any appreciable length could be obtained.

The maximum total thickness of the Prado member in the Valderrueda basin is about 1200 m, but this does not represent the full Prado section as in the Sabero basin younger beds of the Prado member are present. The compiled thickness, including the Sabero section, may be some 2500 m. However, such a complete section is not found anywhere in the considered area or in the Cantabrian region.

Villacorta beds: for purely practical purposes, that is, to provide a recognisable stratigraphic marker and to facilitate map reading, the part of the Prado member between and including the two lower limestone conglomerate horizons has been separated and given a different shade on the map. This part of the Prado section is referred to as the Villacorta beds as they are exposed about 1.5 km east of the village of Villacorta. They can also be studied in the valleys east-northeast of Valderrueda.

The Villacorta beds consist of shales, sandstones and the two bounding limestone conglomerates. Their thickness varies from place to place but 300 m can be considered as the maximum.

The Villacorta beds can be traced in the Tejerina and Ocejo basins but are almost completely absent in the Sabero basin where they only occur in the northeastern corner of the basin, wedging out to the southwest.

The age of the Villacorta beds is Stephanian A, probably lower Stephanian A near Villacorta and higher Stephanian A in the Sabero basin.

In fig. 11 two sections of the Prado member in the Valderrueda basin are given. Section $d_E$—$d_W$ is situated north of Prado de la Guzpeña and has an east-west direction. Its productive part, measured in the Prometida colliery near Prado is represented at a ten times larger scale in the same figure. Section $f_N$—$f_S$ was measured between the villages of Las Muñecas and El Otero. It is much less complete than $d_E$—$d_W$ as rocks belonging to its missing (upper) part have not been found north of the Valderrueda fault system (see p. 126). These younger strata have probably been eroded away from the raised block on which section $f_N$—$f_S$ is situated.

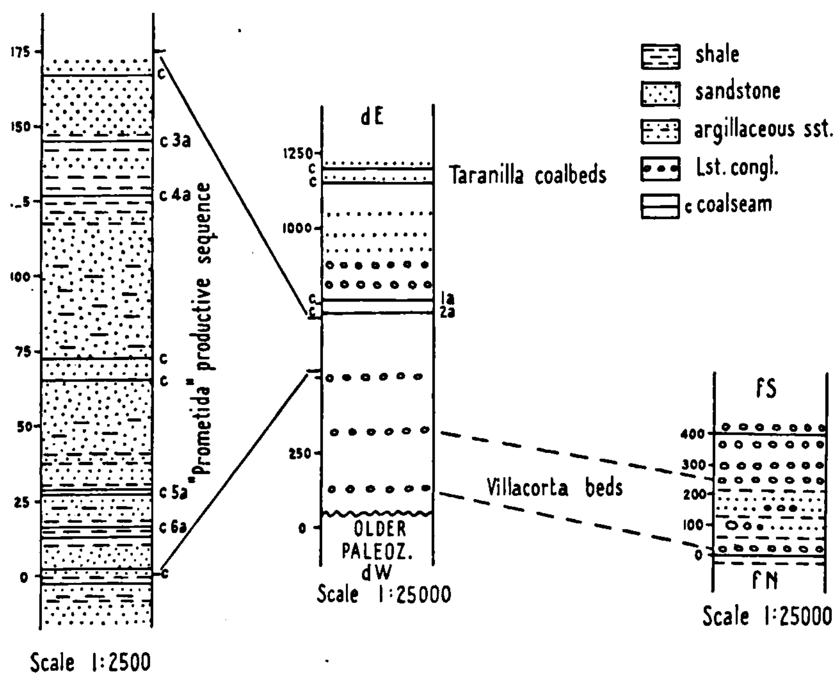


Fig. 11. Sections $d_E$—$d_W$ and $f_N$—$f_S$ of the Prado member, respectively north of Prado and north of El Otero.

Palaeontology and age: from the base of section $d_E$—$d_W$ proper no fossils have been collected. However, a collection of plant fossils could be made on the tip of the coal mine of the M.I.L.E.S.A. company near Soto de Valderrueda. In this mine production is obtained from coal seams just above and possibly also in the Villacorta beds (base of Prado member). The following species were determined by Professor F. Stockmans.

Collection Soto de Valderrueda (M.I.L.E.S.A.):

*Lepidodendron dissitum* SAUVEUR
*Lepidophloios* sp.
*Lepidophyllum anthemis* (KOENIG)
*Lepidostrobus?* nov. sp.
*Pecopteris ambigua* (STERNBERG)
*Pecopteris polymorpha* BRONGNIART
*Acitheca polymorpha* BRONGNIART
*Pecopteris unita* BRONGNIART
cf. *Pecopteridium jongmansi* P. BERTRAND
*Odontopteris reichiana* GUTBIER
*Mixoneura ovata* (HOFFMANN)
*Mixoneura peyerimhoffi* P. BERTRAND
*Neuropteris scheuchzeri* HOFFMANN
*Linopteris brongniarti* (BUNBURY) abundant
*Linopteris obliqua* BUNBURY
*Dicksonites pluckeneti* STERZEL
*Potoniea* sp.
*Pseudomariopteris busqueti* (ZEILLER)
*P. busqueti* GRAND'EURY
*Sphenopteris dimorpha* WAGNER (non LESQUEREUX)
*Sphenophyllum emarginatum* BRONGNIART
*Asterophyllites equisetiformis* (SCHLOTHEIM)
*Annularia sphenophylloides* (ZENKER)
*Annularia stellata* (SCHLOTHEIM)
*Calamites* sp.
*Calamostachys germanica* WEISS
*Calamostachys tuberculata* (STERNBERG)
*Aphlebia* sp.

(*Spirorbis* sp.)

This assemblage shows a mixture of Westphalian D and Stephanian elements and the most probable age indicated by it is lower Stephanian A (Stockmans, pers. comm.).

On the tip of the mine "Prometida" near Prado de la Guzpeña the following species were found by Prof. Stockmans (see Stockmans, in press).

Collection Prado de la Guzpeña:

*Lepidophloios* sp.
*Lepidostrobus* sp.
*Lepidophyllum acuminatum* LESQUEREUX
*Sigillaria scutellata* BRONGNIART
*Sigillariostrobus* sp.
*Annularia sphenophylloides* (ZENKER)
*Asterophyllites equisetiformis* (SCHLOTHEIM)
*Calamites* sp.
*Sphenophyllum oblongifolium* (GERMAR & KAULFUSS)
*Poacordaites linearis* GRAND'EURY
*Pecopteris (Ptychocarpus) unita* BRONGNIART
*Pecopteris (Acitheca) polymorpha* BRONGNIART
*Pecopteris (Asterotheca) cyathea* (SCHLOTHEIM)

*Pecopteris martinezi* STOCKMANS & WILLIÈRE
*Pecopteris prometidae* STOCKMANS & WILLIÈRE
*Alethopteris zeilleri* WAGNER
*Callipteridium striatum* WAGNER
*Callipteridium ibericum* STOCKMANS & WILLIÈRE
*Dicksonites pluckeneti* (SCHLOTHEIM)
*Linopteris neuropteroides* (GUTBIER)
*Linopteris obliqua* (BUNBURY)

A Stephanian A age is clearly indicated by this assemblage (Stockmans, in press).

Wagner (1964) published a list of plant species from the same locality and reached the same conclusion on the age of the Prado strata.

Southeast of San Martín de Valdetuejar a few fossil plant specimens were collected on the tip of an abandoned mine. The following species have been recognized (determination Stockmans).

Collection Locality 182 (Helmig)

*Lepidophyllum lanceolatum* L. & H.
*Linopteris obliqua* (BUNBURY)
*Dicksonites pluckeneti* (STERZEL)
*Callipteridium gigas* (GUTBIER)
*Sphenophyllum oblongifolium* GERMAR & KAULFUSS
*Annularia stellata* (SCHLOTHEIM)
*Annularia sphenophylloides* (ZENKER)
*Neuropteris scheuchzeri* HOFFMANN

This list is obviously incomplete, and little more can be said of it than that it seems to indicate a Stephanian A age.

The palaeobotanic evidence given above suggests that the section $d_E$—$d_W$ comprises more or less the lower half of the Stephanian A.

Fauna: marine fossils were found in the Prado of the Valderrueda basin in a few places. About 50 m southeast of a coal mine which in turn lies some 500 m southeast of El Otero, several brachiopods, trilobite pygidia and other faunal fragments were collected from a shale band of 1 to 2 m thickness. Stratigraphically about 10 to 30 m lower lies the coal bed which is being worked in the above-mentioned mine. The same marine shale band, though only some 30 cm thick, is also found on the western bank of the Taranilla brook, about 900 m southwest of the former locality.

Another outcrop of marine shale occurs approximately 500 m east-southeast of Villalmonte. There brachiopod, gastropod and coral fragments plus a few trilobite pygidia were found.

In another exposure, some 200 m west-southwest of the former one, a porous sandstone (less than 0.5 m thick) containing abundant brachiopod and lamellibranch casts is found immediately overlain by shales with plant impressions *(Neuropteris sp. ?scheuchzeri?, Mixoneura ovata)*.

The fauna has not yet been determined.

Economic aspects: due to the sedimentary and tectonic irregularity of the Prado member, no estimates of the possible coal reserves can be given. In comparison to the Carrión member the Prado is much poorer in coal content. The concessions are generally small, with the exception of those of Hulleras de Prado, S.A. The exploitation of most concessions is often interrupted for longer periods and changes of ownership are frequent.

## *The Tejerina basin*

*The unconformable contact*

On the map it is obvious that the Cea beds in the Tejerina syncline lie unconformably upon the paralic Yuso sequence. Still, in the field very few outcrops exist in which an irrefutably unconformable contact between Yuso and Cea beds can be observed from close range. Only two such outcrops are known to the present author. The first one is in the south flank of the Tejerina syncline, along the path from Prioro to Salio. There the basal quartzite conglomerate of the Cea is only 0.5 to 1 m thick, and it cuts off the underlying Yuso beds at an angle of 10 to 20 degrees (fig. 12).

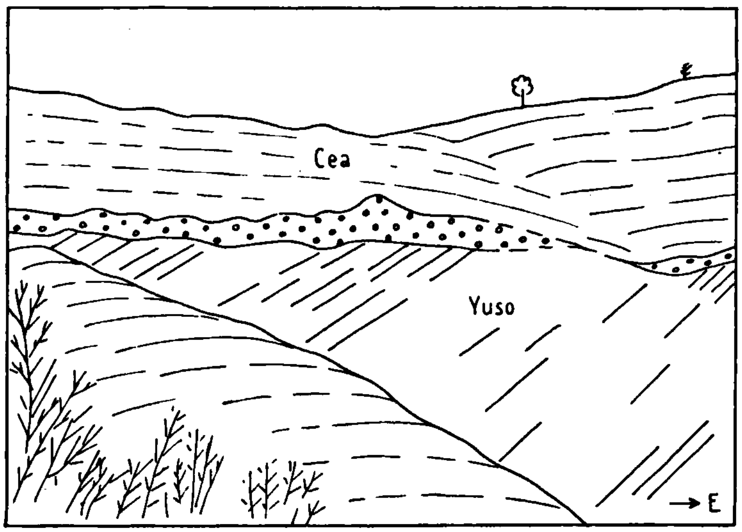


Fig. 12. Unconformity between Yuso and Cea beds in the south flank of the Tejerina syncline. (Drawing after photograph.)

The other, more convincing example of the unconformity between the Yuso and the Cea in the Tejerina basin was pointed out to the author by Mr. J. F. Savage, M. Sc. In this outcrop, which lies some 700 m east of the former one in the axial part of the syncline, flat-lying Cea conglomerates overlie previously folded and eroded Yuso shales (fig. 13). This outcrop is easily overlooked, as the flat-lying cleavage in the steeply dipping part of the Yuso beds is more conspicuous than the bedding on first sight (fig. 14).

*Subdivision*

In the Tejerina basin the twofold subdivision of the Cea formation is equally applicable.

*The Carrión member.* — Here the Carrión member consists almost exclusively of quartzite conglomerates with intercalated shales. Only in the northwestern corner of the basin, north of Remolina, a limestone conglomerate bed (with a thickness varying from 20 m in the west to 0 m in the east) occurs under the quartzite conglomerates. The limestone conglomerate splits up into three beds which interfinger with the quartzite conglomerates and wedge out to the east. North of Remolina this

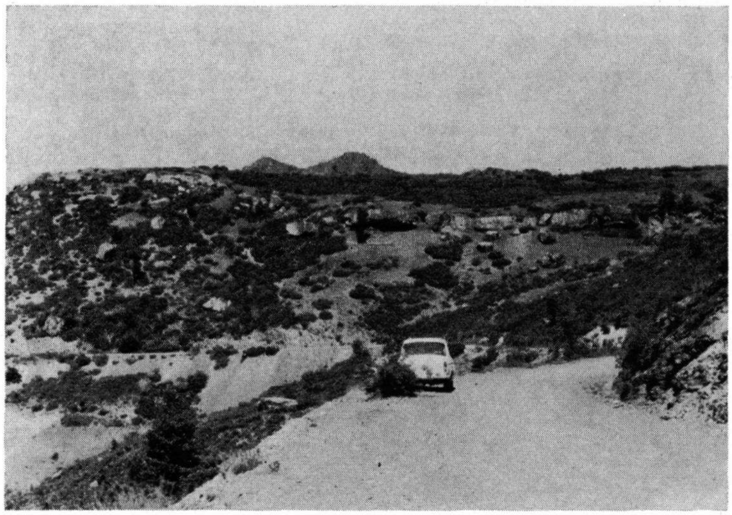

Fig. 13. Flat-lying Cea quartzite conglomerate overlying steep dipping Yuso strata near the Pando pass.

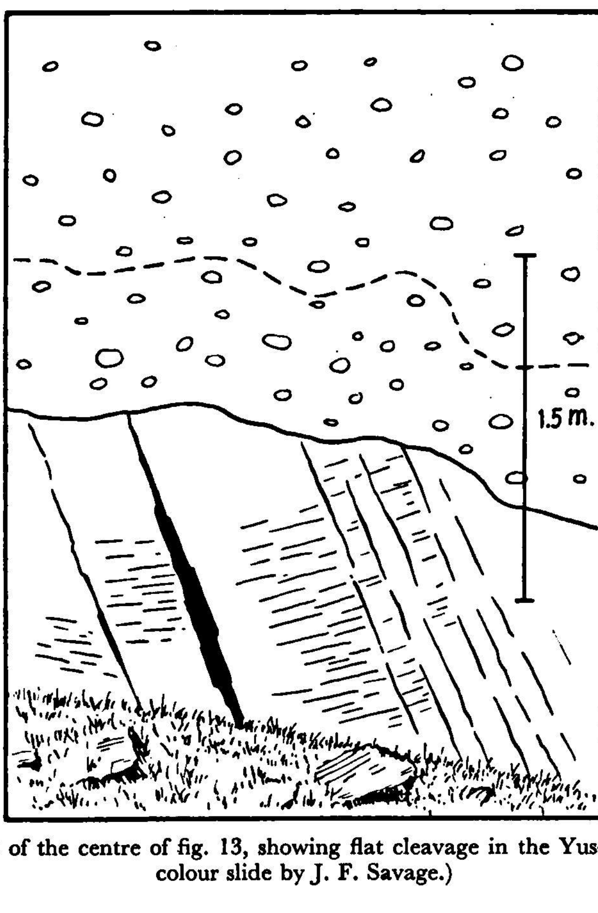


Fig. 14. Detail of the centre of fig. 13, showing flat cleavage in the Yuso. (Drawing after colour slide by J. F. Savage.)

limestone conglomerate is in its turn underlain by a few tens of metres of shales which also thin out to the east. The occurrence of these exceptional Carrión limestone conglomerates is readily explained by the presence of 1) the Carboniferous limestones of the Pico Jano massive which they directly overlie in this place and 2) the fault zone of the León line immediately north of the Tejerina basin.

Three to four separate quartzite conglomerate beds were observed in the Carrión member in the Tejerina syncline. In the western part of the basin they are separated either by the above-mentioned limestone conglomerates or by relatively thin shale intercalations which thicken to the south and east, while the conglomerate beds

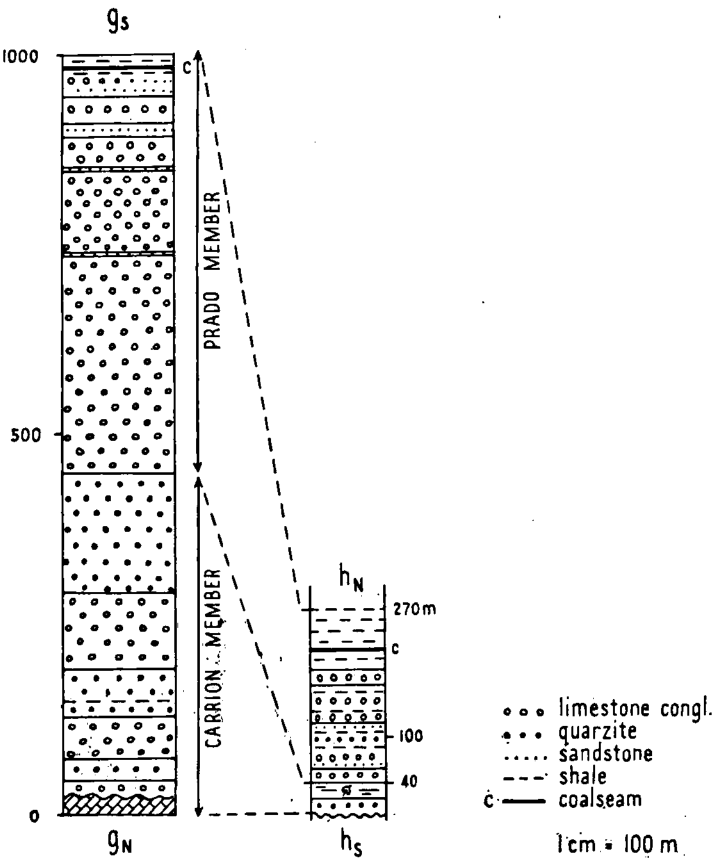


Fig. 15. Sections $g_N$—$g_S$ and $h_N$—$h_S$, respectively of the north and south flanks of the Tejerina syncline.

become thinner in that direction. In the north flank of the Tejerina syncline north of Tejerina the Carrión is about 450 m thick (fig. 15, section $g_N$—$g_S$), and in the south flank, south of Tejerina, 250 m.

North of Prioro the Carrión member in the south flank of the Tejerina syncline is even reduced to a mere 40 m of quartzite conglomerate and shale (fig. 15, section $h_N$—$h_S$).

Palaeontology and age: the few fossil plants found under the limestone conglomerates in the south flank of the Tejerina syncline allow no conclusive dating. They only indicate that the Carrión member here may be either of uppermost Westphalian D or of Stephanian A age. The following species have been found: by Henkes (1959, Locality 356, determination by R. H. Wagner)

*Neuropteris scheuchzeri* HOFFMANN
cf. *Lobatopteris alloiopteroides* WAGNER
*Lepidodendron* sp.
*Sphenophyllum emarginatum* (BRONGNIART)
*Alethopteris* sp.

By Mr. J. F. Savage (Loc. 71 & 80) (determination by van Amerom)

(71)

*Sigillariophyllum*
*Pecopteris* sp.
*Annularia stellata* (SCHLOTHEIM)
*Asterophyllites equisetiformis* SCHLOTHEIM
*Sphenophyllum* cf. *emarginatum* BRONGNIART
*Sublepidodendron lycopodioides* (STERNBERG) NATHORST
cf. *Callipteridium* sp.

(80)

cf. *Calamites* sp.
cf. *Astheroteca* aff. *cyathea-arborescens*

By the present author (Loc. 1532 Helmig, probably same as Henkes' Loc. 356)

*Neuropteris scheuchzeri* HOFFMANN
*Alethopteris grandini* BRONGNIART
*Annularia stellata* (SCHLOTHEIM)
*Pecopteris* sp.

Wagner (1962, 1964) placed an assemblage from the base of the Cea sequence in the Tejerina basin in the upper Westphalian D.

*The Prado member.* - In the Tejerina basin the Prado member consists for the greater part of limestone conglomerate. In the north flank of the syncline the limestone conglomerates reach a maximum thickness of about 600 m (fig. 14), but they thin out rapidly to the south. In the south flank of the Tejerina syncline there are only two to three bands of limestone conglomerate of 5 to 20 m thickness separated by shales and sandstones with a few coal seams. Section $h_N$—$h_S$ (fig. 14) of the south flank is situated approximately 2 km north of Prioro.

Palaeontology and age: the plants that have been collected from the Prado member, that is from between or above the limestone conglomerates, by Henkes as well as by the present author, are listed below under their respective locality numbers.
From the north flank (Section $g_N$—$g_S$)
Localities 870, 875 and 876 (Henkes, 1959), determ. Wagner

*Callipteridium gigas* (GUTBIER)
*Callipteridium pteridium* ZEILLER
*Alethopteris* cf. *grandinioides* KESSLER
*Alethopteris* sp.
*Neuropteris scheuchzeri* HOFFMANN

*Linopteris?* cf. *neuropteroides* Potonié
*Pecopteris* sp.
*Annularia sphenophylloides* Zenker
*Annularia stellata* Schlotheim

From the south flank (Section $h_N$—$h_S$)

Localities 593, 594 and 499 (Henkes, 1959) determ. Wagner

*Callipteridium gigas* (Gutbier)
*Callipteridium pteridium* Zeiller
*Alethopteris kamissii* Wagner
*Odontopteris* cf. *obtusa* Brongniart
*Odontopteris* cf. *reichi-brardi*
*Odontopteris* sp.
*Pecopteris dentata* Brongniart
*Pecopteris* sp.
*Annularia stellata* (Schlotheim)
*Lepidodendron geinitzii* (?)
*Lepidodendron* sp.

From the tip of an abandoned coal mine, roughly 600 m southwest of Tejerina, the present author collected the following species (determination by van Amerom.):

*Odontopteris minor-zeilleri* H. Potonié
*Linopteris obliqua* Bunbury
*Alethopteris grandini* Brongniart
*Sphenophyllum* sp.
*Pecopteris polymorpha* Brongniart
*Pecopteris* sp.
Sporangiae of *Annularia (Calamostachys)*

These assemblages point to a Stephanian A age for the Prado sediments in the Tejerina basin. Wagner (1962b, 1964) indicates a lower Stephanian A age for the upper part of the Cea sequence here, on the basis of more complete assemblages than given in the present paper.

Economic aspects: No data about the coal exploitation in the Tejerina basin are available to the present author. It is not likely that any important production has ever been obtained from the Tejerina syncline in the past, nor that it will ever be in the future. At present all mining activity in the area has ceased.

Salio inlier: North of the Tejerina basin a small, probably infaulted patch of Cea shales and sandstones with carbonaceous intercalations is found. It is known as the Salio inlier.

Henkes (1959) reported the collection of *Pecopteris hemitelioides* Brongniart and *Callipteridium pteridium* Zeiller from the Salio shales, which indicate a Stephanian A age.

### *The Ocejo basin*

*The unconformable contact*

In the Ocejo basin the best examples of the unconformable nature of the Cea group are found.

Between Santaolaja de la Varga and Ocejo de la Peña flatlying Cea limestone conglomerates or shale and sandstone overlie vertical Upper Devonian quartzites and Lower Carboniferous limestones (figs. 16—19).

Fig. 16. Flat-lying Cea shale and limestone conglomerate overlying steep dipping Caliza de Montaña and Upper Devonian quartzites northeast of Santaolaja. Direction of photo looking southwest.

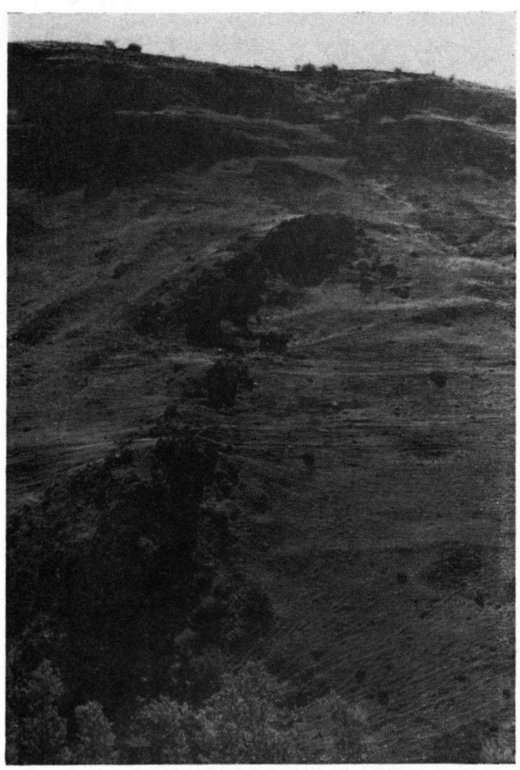

Fig. 17. Cea limestone conglomerate (exposed along strike) truncating Upper Devonian bed dipping steeply to the east, approximately 250 m east of Santaolaja.

Fig. 18. Unconformity between flat-lying Carrión shale with carbonaceous streaks and plants and subvertical Upper Devonian quartzite, east of the bridge along the path to Ocejo.

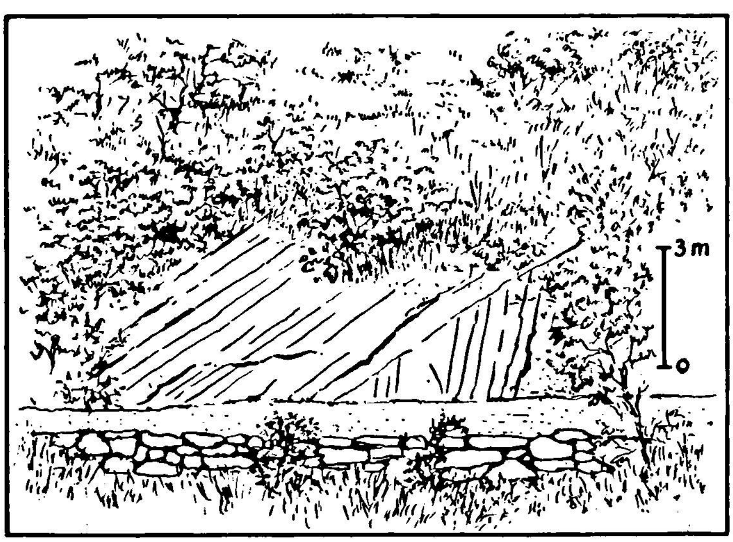


Fig. 19. Carrión quartzitic sandstone truncating Upper Devonian quartzite. Same place as 18, west of bridge. Drawing after photograph.

Other outcrops of the same unconformity can be observed on the Peña Rionda and the Pico Cerroso, northwest of Ocejo.

*Subdivision*

Again the twofold subdivision of the Cea formation can be recognised at least in some parts of the Ocejo basin.

*The Carrión member.* — In the Ocejo basin the Carrión member is represented by up to 50 m of shale with sandy intercalations and a few coal seams, overlain by 1 to 10 m of quartzitic sandstone.

Some 1500 m northeast of Santaolaja the Carrión consists of about 180 m red beds which have been described in detail by Oele and Mabesoone (1963).

As in the Valderrueda basin the Carrión member is not everywhere represented in the Ocejo basin, and in several places the Prado limestone conglomerates rest directly on pre-Cea rocks. Also the thickness of the Carrión is extremely variable, but nowhere does it seem to exceed 50 m in the Ocejo basin, except in the abovementioned red bed facies.

Paleontology and age: the author's collection from the tip of a coal mine just outside Ocejo comprises the following species (determination Stockmans):

*Lepidodendron obovatum* STERNBERG
*Lepidostrobus variabilis* LINDLEY & HUTTON
*Asterotheca* sp.
*Pecopteris plumosa-dentata* (ARTIS-BRONGNIART)
*Pecopteris unita* BRONGNIART
*Alethopteris grandini* (BRONGNIART)
*Linopteris obliqua* (BUNBURY)
*Mixoneura ovata* (HOFFMANN)
*Neuropteris scheuchzeri* HOFFMANN
?cf. *Mariopteris beyrichi* (STUR)
*Hymenotheca weissi* (SCHIMPER)
*Sphenophyllum emarginatum* BRONGNIART
*Annularia stellata* (SCHLOTHEIM)
*Annularia sphenophylloides* (ZENKER)
*Calamostachys tuberculata* (STERNBERG)
*Calamostachis germanica* WEISS
*Myriophyllites* sp.

From an outcrop of the basal shales of the Cea north of Ocejo the author collected the following species (determination Stockmans):

*Pecopteris macronervosa* P. CORSIN
*Pecopteris unita* BRONGNIART
*Pecopteris cyathea* (SCHLOTHEIM)
*Pecopteris ambigua* NEMEJC
*Pecopteris* sp.
*Asterotheca* sp.
*Alethopteris grandini* (BRONGNIART)
*Callipteridium jongmansi* (P. BERTRAND)
*Linopteris neuropteroides* (GUTBIER)
*Linopteris obliqua* (BUNBURY)

*Linopteris* sp.
*Mariopteris nervosa* (Brongniart)
*Dicksonites pluckeneti* (Schlotheim)
*Cordaites* sp.
*Sphenophyllum emarginatum* Brongniart
*Sphenophyllum truncatum* Schimper
*Calamostachys tuberculata* (Sternberg)
*Asterophyllites equisetiformis* (Schlotheim)
*Annularia stellata* (Schlotheim)
*Annularia sphenophylloides* (Zenker)

The above-mentioned assemblages indicate an upper Westphalian D age for the shales in which they occur.

On the basis of collections made in the same localities Wagner (1959b, 1964) also placed the entire sequence, including the overlying limestone conglomerates, in the upper Westphalian D.

Economic aspects: some coal production has been obtained from the Carrión member in the Ocejo basin, but it has probably never been very important in comparison to, for instance, that of the Valderrueda basin. At the present date coal production is diminishing, and only one mine, near Ocejo, is still in operation. The coal beds are reportedly very irregular in thickness; pockets of many metres thick occur, but mostly coal thickness is below the limit of profitable exploitation.

*The Prado member.* — In the Ocejo basin the Prado member is represented by limestone conglomerates and intercalated shales and sandstones. There are mainly four to six separate limestone conglomerate beds of 5 to 20 m each. They thin out towards the south and the west while the shale intercalations become thicker in those directions. The conglomerates and shales together may reach a maximum thickness of about 400 m (see section G, App. III).

In several places the limestone conglomerates overlie rocks of the Carrión member, but everywhere else in the Ocejo basin they rest immediately on Lower Carboniferous or Devonian rocks (figs. 16, 17).

To the author's knowledge no determinable fossils have yet been found between the limestone conglomerates in the Ocejo basin. However, in view of the close relation of the latter basin with the adjacent Valderrueda and Tejerina basins, it seems safe to assume that the Prado member in the Ocejo basin is also of Stephanian A age.

## *The Sabero basin*

### *The unconformable contact*

No exposures have been found by the present author in which the actual unconformable contact between Older Palaeozoic rocks and the Cea sediments of the Sabero basin can be observed. But in several localities along the northern boundary of the basin it is clearly demonstrable that such a contact exists. Along the southern border of the Sabero basin this contact is in most places disturbed by faulting.

### *Subdivision*

*The Carrión member.* — In the northeastern corner of the Sabero basin, near Alejico, some beds occur under the lowest limestone conglomerate which may be compared to the Carrión member in the other basins. They are 50 to 100 m of shales and sandstones with some coal seams and a few thin quartzite conglomerate lenses.

Palaeontology and age: the few plants found on the tip of the coal mine near Alejico belong to the following species (determination Stockmans):

*Lepidodendron dissitum* SAUVEUR
*Pecopteris arborescens* (SCHLOTHEIM)
*Alethopteris grandini* (BRONGNIART)
*Mixoneura ovata* (HOFFMANN)
*Alloiopteris* sp.
*Sphenophyllum oblongifolium* (GERMAR & KAULFUSS)
*Sphenophyllum emarginatum* BRONGNIART
*Sigillaria* sp.

This collection is too small to warrant any difinitive conclusions about its exact age, but as an assemblage it indicates a Stephanian A age. It seems therefore, that the Carrión member is somewhat diachronous, being of upper Westphalian D age near Ocejo and Stephanian A near Alejico. Wagner's sketch and map, (1964, p. 836) imply that the Sabero basin is a separate basin of upper Stephanian rocks which unconformably overlie the upper Westphalian D strata of the Ocejo basin. However the field data leave little doubt that the Sabero basin is a normal continuation of the Ocejo basin and that, for instance, the lowest limestone conglomerates in the two basins may be compared with each other.

Economic aspects: in the above-mentioned colliery near Alejico one or two coal beds are mined. No data about this mine and its production are available to the author. However, it seems to compare favorably with the Ocejo mines.

*The Prado member.* — The Prado member in the Sabero basin is represented by a series of some 1000 to 1500 m thickness. It consists mainly of shales and sandstones with coal beds and some limestone and quartzite conglomerate bands or lenses in its lower part. The limestone conglomerates are thickest in the northeastern corner of the basin and thin out to the southwest. In section $k_N$—$k_S$, which has been measured partly in the mines and partly on the surface, the stratigraphy of the north flank of the Sabero syncline is represented (fig. 20).

No section of the south flank can be given as most of it has been faulted away, and the remaining part is tectonically disturbed.

Paleontology and age: a few collections of fossil plants were made in the Sotillos mine. They are all indicated in section $k_N$—$k_S$ (fig. 20).

The collection from the roof of the coal bed "Estrecha" in the northern mining-group ("Paquete Norte") comes from the lowest part of the Prado member in the Sabero basin. The species in this collection, as determined by Prof. Stockmans, are given in the following list.

*Pecopteris polymorpha* BRONGNIART
*Acitheca polymorpha* (BRONGNIART)
*Pecopteris lepidorachis* BRONGNIART
*Asterotheca lepidorachis* (BRONGNIART)
*Pecopteris feminaeformis* (SCHLOTHEIM)
*Pecopteris plumosa-dentata* ARTIS-BRONGNIART
*Pecopteris viannae* TEIXEIRA
*Pecopteris platoni* GRAND'EURY
*Pecopteris bredovi* GERMAR
*Pecopteris unita* BRONGNIART

*Pecopteris acuta* Brongniart
*Pecopteris waltoni* P. Corsin
*Pecopteris* sp.
*Asterotheca* sp.
*Asterotheca cyathea* (Schlotheim)
*Mixoneura ovata* (Hoffmann)
*Neuropteris* sp.
*Sphenopteris* sp.
*Sphenophyllum oblongifolium* (Germar & Kaulfuss)
*Sphenophyllum* cf. *Sphenophyllostachys* sp.
*Annularia sphenophylloides* (Zenker)

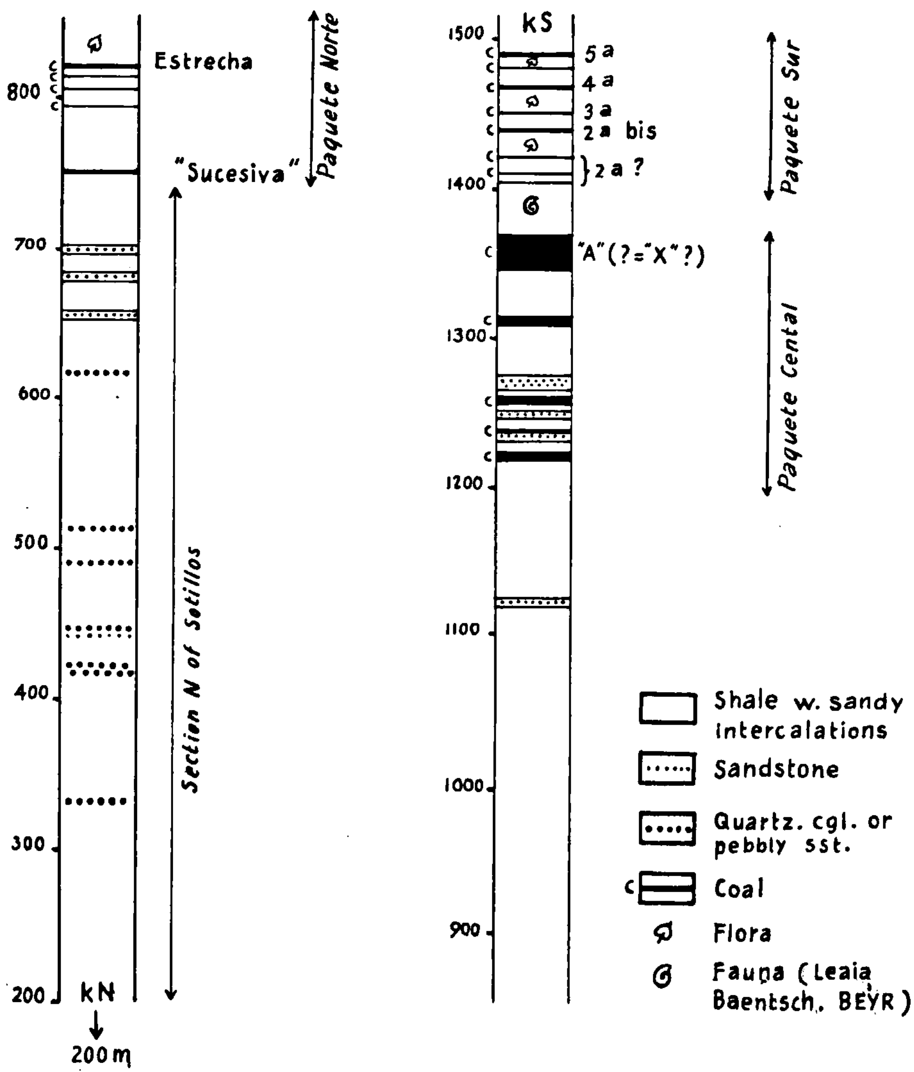


Fig. 20. Section $k_N$—$k_S$ of the north flank of the Sabero syncline.

*Annularia stellata* (SCHLOTHEIM)
*Lepidophyllum anthemis* (KÖNIG)
*Lepidodendron* sp.
*Lepidodendron dissitum* SAUVEUR
*Sigillaria brardi* BRONGNIART
*Poacordaites linearis* GRAND'EURY
*Cordaitanthus acicularis* (RENAULT)
*Calamites* sp.
*Calamostachys germanica* WEISS
*Calamostachys tuberculata* (STERNBERG)
*Cantheliophorus* sp.

From several places in the central mining-group ("Paquete Central") the following assemblage was derived (determination Stockmans)

*Pecopteris polymorpha* BRONGNIART
*Pecopteris lepidorachis* BRONGNIART
*Pecopteris unita* BRONGNIART
*Pecopteris* sp.
*Asterotheca* sp.
*Alethopteris grandini* (BRONGNIART)
*Callipteridium gigas* (GUTBIER)
*Mixoneura ovata* (HOFFMANN)
*Sphenopteris* sp.
*Sphenophyllum oblongifolium* (GERMAR & KAULFUSS)
*Calamites* sp.
*Calamostachys*
*Annularia sphenophylloides* (ZENKER)

From the immediate vicinity of the coal beds "2" and "4" of the southern mining-group ("Paquete Sur"), in the cross-cut 3W 7mo Recorte, the following species were collected (determination Stockmans).

*Lepidodendron dissitum* SAUVEUR
*Lepidophyllum anthemis* (KÖNIG)
*Lepidophyllum* sp.
*Pecopteris polymorpha* BRONGNIART
*Acitheca polymorpha* (BRONGNIART)
*Pecopteris* sp.
*Pecopteris saraepontana* STUR
*Pecopteris feminaeformis* (SCHLOTHEIM)
*Pecopteris acuta* BRONGNIART
*Callipteridium gigas* (GUTBIER)
*Mixoneura ovata* (HOFFMANN)
*Linopteris brongniarti* (GUTBIER)
*Pseudomariopteris ribeyroni* (ZEILLER)
Cf. *Pseudomariopteris corsini* (TEIXEIRA) WAGNER
*Sphenopteris* sp.
*Annularia sphenophylloides* (ZENKER)
*Calamostachys tuberculata* (STERNBERG)
*Calamites* sp.
*Sigillaria brardi* BRONGNIART

Spores of *Sigillaria*
Strobiles of *Lycopodiae*

Also from the southern mining-group, in cross-cut 2W17S, come the following species (determination Stockmans).

From the roof of coal bed "2":

*Zygopteris pinnata* (GRAND'EURY) (sporangiums)
*Pecopteris feminaeformis* (SCHLOTHEIM)
*Callipteridium gigas* (GUTBIER)
*Mixoneura ovata* (HOFFMANN)
*Pseudomariopteris ribeyroni* (ZEILLER)
*Poacordaites linearis* GRAND'EURY
*Annularia sphenophylloides* (ZENKER)
*Asterotheca* sp.
*Asterophyllites equisetiformis* (SCHLOTHEIM)

From coal bed "4":

*Lepidophyllum anthemis* (KÖNIG)
*Pecopteris polymorpha* BRONGNIART
*Pecopteris corsini* WAGNER
*Dicksonites sterzeli* (ZEILLER)
*Acitheca polymorpha* (BRONGNIART)
*Mixoneura ovata* (HOFFMANN)
*Pseudomariopteris ribeyroni* (ZEILLER)
*Sphenopteris* sp.
*Annularia sphenophylloides* (ZENKER)
*Sigillariastrobus* sp.
*Sigillaria brardi* BRONGNIART

All the above-mentioned plant-assemblages from the Prado member of the Sabero basin indicate a (probably upper) Stephanian A age (Stockmans, pers. comm.).

In spite of the fact that coal bed Estrecha of the northern mining group and coal bed "4" of the southern mining group are separated by some 600 m of stratigraphy, their associated floras do not differ appreciably. This has given rise to the suspicion that at least part of the stratigraphy of the Sabero north flank has been tectonically repeated, and that section $k_N$—$k_S$ shows an exaggerated thickness. This will be further discussed below (p. 137).

The present author has found plant associations in the Sabero basin which were exclusively of Stephanian A age, as shown on the preceding pages. Nevertheless, some reports exist of finds of younger floral elements in this basin.

In a collection made by Prof. Stockmans (see Stockmans, in press) on the general tip of the Sotillos colliery a specimen of *Neuropteris gallica* occurs, a species that is usually found higher in the stratigraphy. It is well possible that the highest strata of the Sabero basin are of Stephanian B age. After all, the general tip of Sotillos is a mixture of debris from all mining operations in the Sotillos area, which involve at least 600 m of stratigraphy.

Wagner (1957) gives a list of plant fossils, collected on the general tip of the La Herrera mines, on the basis of which he concludes to a Stephanian B (C?) age for the entire Sabero section. This is not confirmed by the present results and, as in the former case, it is probable that the younger species come from the highest parts of the section, which may be of Stephanian B age.

Fauna: In the cross-cut 3W 2S at 342 m from the general gallery (see section $k_N$—$k_S$, fig. 20), a few specimens were found of *Leaia baentschiana* Beyrich, a fresh-water phyllopod the occurrence of which is generally restricted to the Stephanian.

Economic aspects: with the available data it is impossible to give a reliable estimate of the coal reserves of the entire Sabero basin. A rough estimate will be given for the concessions of Hulleras de Sabero, S.A. It should be noted that the accuracy of any estimate of the Sabero coal reserves will be very poor because of the extreme variations in thickness of the coal beds, especially in the axial part of the basin, due to tectonic causes.

Sedimentary and structural evidence indicate the probability that the thickness and purity of the coal beds in the north flank of the Sabero syncline increase laterally towards the south, i.e. downwards.

Estimated coal reserves of the mining company Hulleras de Sabero y Anexas, S.A. (for exploitation down to 500 m above sea level):

Paquete Norte:

Average coal thickness 1.5 m
Maximum extent 7000 m
Average width 600 m
Capacity: 1.5 × 7000 × 600 = 6.3 million cubic metres.
Average spec. gravity coal 1.25.
Gross tonnage 6.3 × 1.25 = 7.875 mill metric tons.
Allowing for 30 % loss due to sedimentary and tectonic irregularities the reserves of the Paquete Norte are approximately 5.5 million metric tons.

Paquete Central:

Average coal thickness 6 m
Maximum. extent 750 m
Average width 500 m
Capacity: 6 × 750 × 500 = 2.25 million cubic metres.
Av. spec. gravity coal 1.25.
Gross tonnage 2.25 × 1.25 = 2.8125 million metric tons.
Allowing for 40 % loss, the reserves of the Paquete Central are approximately 1.7 million metric tons.

Paquete Sur:

Average coal thickness 5 m
Maximum extent 4000 m
Average width 700 m
Capacity: 5 × 4000 × 700 = 14 million cubic metres.
Gross tonnage (spec. gravity 1.25) 14 × 1.25 = 17.5 million metric tons.
Allowing for 40 % loss, the reserves of the Paquete Sur are approximately 10.5 million metric tons.

The total reserves of Hulleras de Sabero y Anexas, S.A. are then:

| | |
|---|---|
| Paquete Norte: | 5.5 million metric tons |
| Paquete Central: | 1.7 million metric tons |
| Paquete Sur: | 10.5 million metric tons |
| Total | 17.7 million metric tons |

## YOUNGER FORMATIONS

### *Cretaceous*

*Wealden facies*

A great part of the Palaeozoic core of the Cantabrian Mountains is bordered to the south by continental sediments which are comparable to the Wealden facies of the English Cretaceous. They are red to pink clays, white to pink kaolinic sands and gravels with lignitic streaks and lenses. The Wealden sequence may reach a thickness of some 600 m between Boñar and Colle, but this may be considered as exceptional, normally it is less than 250 m thick.

The age determinations of the Wealden clearly indicate that it is a diachronous deposit. In the east, in the province of Burgos, it is reported to be of Albian age (Ciry, 1939), while in the west, near Aviados in the province of León, pollen from lignitic lenses point to a Turonian age (van Amerom, in press).

In several places the Wealden deposits are or have been exploited for their clays (tile and brick works) as well as for their sands (refractory bricks).

*Marine facies*

The limestones and marls of the marine Cretaceous are stratigraphically superposed on the Wealden deposits. The individual limestone or marl beds are separated by intercalations of more clastic sediment. In the studied area the marine Cretaceous is best developed between Boñar and Colle. (The somewhat anomalous thicknesses there caused Ciry (1939) to suggest the existence of a separate small basin in this part of the area during the Upper Cretaceous).

South of the Sabero basin the marine Cretaceous has an average thickness of about 400 m. To the east its limestone and marl bands diminish in number and in thickness, and besides it is gradually cut off by the unconformable Upper Tertiary.

Between Yugueros, west of the Esla river, and Quintana de la Peña, east of the Esla, only sporadic outcrops of the Cretaceous limestone occur.

Near Prado de la Guzpeña the limestones appear at the surface again, with a thickness of roughly 250 m.

Near Puente Almuhey they are cut off by the alluvial deposits of the Cea river to reappear in an isolated outcrop south of Soto de Valderrueda.

Further to the east, between Soto and La Espina no Cretaceous outcrops occur; in that stretch the Cea sediments are in direct contact with the unconformable Upper Tertiary.

Southeast of the La Espina railway station, the Cretaceous limestones are exposed again, marking an isolated exposure of the Southern Border Fault.

Further to the east the marine Cretaceous only appears from the left bank of the Carrión river to the east, in the area recently described by Koopmans (1962).

The age of the marine Cretaceous in the considered area ranges from Campanian to Maestrichtian according to Ciry (1939). The limestones are in places richly fossiliferous and their dating seems to present no great problem.

In some places the Cretaceous limestones are quarried for cement and cement-brick works, as well as for road metal.

### *Tertiary*

Along the southern boundary of the studied area the Cretaceous and in some places also the Cea rocks are covered by Tertiary sediments of the Duero basin. They are mostly reddish continental deposits, which were clearly derived from the rising Cantabrian mountain chain.

As far as the author knows, no determinable fossils have ever been found in the Tertiary in or near the area considered in this paper. The subdivision into Lower and Upper Tertiary here is based on the existence of an angular unconformity between those two units, and the ages given follow Mabesoone (1959), who based his conclusions on lithologic correlations with other areas where fossils have been found.

*Lower Tertiary*

The greater part of the Lower Tertiary in the studied area is made up of conglomerates with a high limestone pebble content and a reddish sandstone. Mabesoone (1959) reports that this unit may reach a thickness of nearly 1000 m in the area he investigated (east of the Carrión river).

In the area considered in this paper the Lower Tertiary is exposed in the Esla valley near Cistierna and from west of Yugueros to the Porma river. These Lower Tertiary beds have been put in a steeply south-dipping, vertical or inverted position together with the underlying Cretaceous, presumably during the Savian orogenic phase (upper Oligocene — lower Miocene, Stille, 1924).

The age of the Lower Tertiary deposits (coinciding with the Cuevas facies of Mabesoone, 1959) probably ranges from Eocene to Oligocene.

*Upper Tertiary*

In the investigated area the Upper Tertiary consists almost exclusively of poorly consolidated red beds (sands and clays) with quartzite conglomerate intercalations in its lower part. They probably coincide with the deposits which Mabesoone (1959) called the Vega de Riacos facies.

The red beds either dip to the south at a few degrees or lie in a horizontal position. Between the Carrión and the Esla rivers the Upper Tertiary overlaps onto the Mesozoic or even the Cea deposits and thus covers the Lower Tertiary. The unconformity between the Lower and Upper Tertiary is of a progressive type; the angle of unconformity gradually diminishes towards the south.

The age of the Upper Tertiary is generally assumed to be Miocene.

## *Quaternary*

The Tertiary rocks in the eastern part of the considered area are in many places covered by a deposit of only a few metres thickness, which consist of badly sorted, loose pebbles, gravels and finer material. These deposits are usually called "rañas" (Mabesoone, 1959; Koopmans, 1962) and are considered to be a pediment debris, deposited by intermittent sheetfloods.

The possibility has been mentioned (Mabesoone, 1959) that the rañas be of Villafranchian age, which would imply that they are partly Upper Tertiary. However, this dating is highly conjectural and it seems better to postpone the discussion on this matter until more data on this deposit are available.

The only terrace observed in the studied area occurs along the Carrión river north of Guardo, and has been described by Koopmans (1962, p. 131).

Alluvial deposits occur in the valleys of the more important rivers but they will not be further discussed here.

CHAPTER II

# STRUCTURE

## INTRODUCTION

On the following pages the structure of the Cea formation will be described; for a description of the structure of the Older Palaeozoic rocks reference is made to the paper by Rupke (1965).

Detailed structural mapping of the Cea sediments is seriously hampered by the virtual absence of any consistent marker horizons. The shales, sandstones and coal seams form monotonous cyclic sequences and their isolated outcrops are rarely useful for stratigraphic correlation. The conglomerates are the only rocks that form conspicuous features in the field. But the quartzite conglomerates have a very restricted geographical distribution, and the limestone conglomerates wedge out and split up within short distances, so that the number of limestone conglomerate beds may vary arbitrarily from section to section. This makes it difficult to reconstruct the exact shape of the structures and to give any reliable figures of the throw of the faults which are important structural features of the Cea formation in the studied area.

The Valderrueda basin is structurally by far the most complicated of the four here described. The other three basins can be classified as essentially single-structure basins, that is, they mainly consist of one syncline with some additional minor structures.

The most remarkable general feature is the dependent structural relation between the Cea formation and its underlying rocks. This relation is comparable to that between a crystalline basement and its sedimentary cover. The Older Palaeozoic rocks were folded before the deposition of the Cea formation, and after their main folding phase they seem to have reacted to crustal forces primarily as rigid blocks, moving along their bounding faults mainly in a vertical sense.

An exception to this rule may have to be made for that part of the Older Palaeozoic which is formed by the (Westphalian) Yuso group which was most probably deposited after the main deformation (Curavacas phase, Kanis, 1956; de Sitter, 1961b) of the Lower Carboniferous and older formations. However, Yuso and Cea sediments are in contact with each other only in a small part of the investigated area, namely in the Tejerina and Prioro area. There it can be demonstrated that some structures of the Cea and the Yuso group are coincident, in spite of the strong angular unconformity existing between the groups.

The structure of the Cea formation is generally dominated by synclines which are separated by relatively narrow, elongated, east-west striking fault zones instead of anticlines. Some large anticlines do exist in the Valderrueda basin but they all seem to be closely related to pre-existing positive topographic features in the Older Palaeozoic supra-basement surface. They probably came into being as a result of differential compaction, and most of the ones that have been mapped have a roughly north-south axial direction. They were most probably the earliest structures in the Cea sediments and the now-dominant east-west striking structures were superimposed upon them in later stages of the structural development.

The large east-west striking synclines cover the essentially rigid supra-basement blocks, whereas the fault zones in the Cea cover indicate the faults separating those blocks in the depth. The mainly vertical movements of the supra-basement blocks, tilting or relative uplift and subsidence, caused a lack of space and subsequent folding and faulting in the Cea sediments in the synclines. This secondary deformation probably started near the actual supra-basement faults and gradually migrated toward the axial part of the syncline lying on the downthrown block as the throw along the supra-basement faults grew. The Cea beds are most strongly folded and faulted near the major fault zones.

The general structural aspect of the Cea in the Valderrueda basin is: synclines with disturbed, steep northern flanks and flatter lying, relatively undisturbed southern flanks. The supra-basement faults in this eastern part of the studied area seem to have a downthrow to the south with the exception of the main Valderrueda fault. They are most probably normal faults, but the possibility cannot be excluded that they be reversed faults.

In or south of the Sabero basin all the supra-basement faults have their downthrow to the north, and so the Sabero syncline has a disturbed south flank and an undisturbed north flank. In fig. 21 the general structure-type of the Cea formation in the studied area is schematically represented.

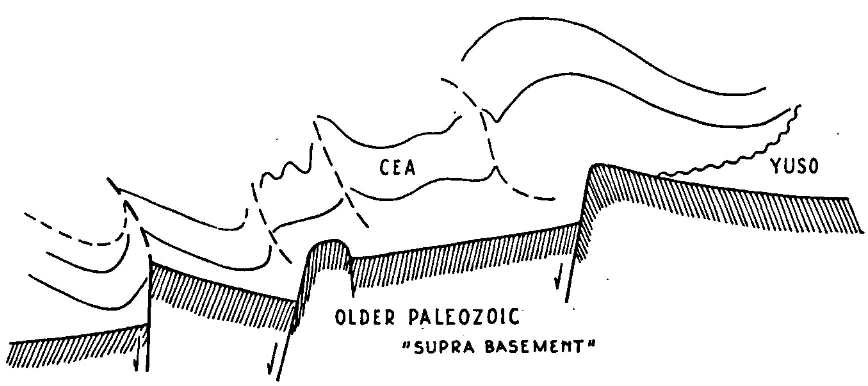


Fig. 21. Diagram of the structure-type of the Cea formation.

Comparable observations have been reported by other authors. Among others by Beloussov (1962) from Russia; by Foose (1960), Norton (1960), Crowell (1960), Osterwald (1961), Berg (1962), Wise (1963), Harrington (1963), Hills (1963), Ham (in Kornfeld, 1964) and Harlton (1964) from the United States; Webb (1963) from Canada; Ziegenhardt (1960) from Germany and Richter (1962) from the western Pyrenees.

General discussions on the mechanics of this structure-type were published, among others by Peive (1960), who called it "fault-folding", and Beloussov (1961).

On the following pages a structural description will be given of the four studied basins in the same succession as in which they were described stratigraphically, the Valderrueda basin, the Tejerina basin, the Ocejo basin and the Sabero basin.

## VALDERRUEDA BASIN

The major east-west structures in the Valderrueda basin will be separately described in an order from south to north. In fig. 22 a structural sketchmap of this basin is given.

The main structures are:
1. the Southern Border Fault
2. the Taranilla-Villacorta syncline
3. the Valderrueda fault system and the Sextíl anticline
4. the Central syncline (Otero and Morgovejo synclines)
5. the Villalmonte fault
6. the Balneario anticlinal zone
7. the Cueto syncline
8. the La Red syncline

1. The Southern Border Fault forms the limit between the Cea formation and the Cretaceous along the southern boundary of the Valderrueda coal basin. The outcrops in which the fault contact was recognised will be described in the following. The boundary between the Palaeozoic and the Cretaceous or younger rocks is formed by the Souther Border Fault only between the Carrión and the Esla rivers. Further to the east, between Guardo and Cervera de Pisuerga, or to the west, south of the Sabero basin, this contact is no longer a fault. There the Upper Cretaceous unconformably overlies the Palaeozoic, but the Cretaceous near the contact has a steep southern, or even inverted, dip and it is clearly involved in a border flexure. No basic difference exists between the border fault and the border flexure, the one being simply a more severe form of the other. Both form part of the great border flexure which separates the Cantabrian mountain chain from the Duero basin.

In several places along the railroad between Prado de la Guzpeña and Puente Almuhey the Southern Border Fault is exposed in a few convincing outcrops. Cea shales, right-side up and dipping to the north, overlie "Wealden" sands and clays (see section K, App. III). Judging from the position of the adjacent younger Cretaceous limestones the "Wealden" strata are inverted and dip steeply to the north. Before reaching Puente Almuhey the Southern Border Fault disappears under the alluvium of the Taranilla valley. North of Puente, where the fault apparently swings to the north, it is covered by Upper Tertiary conglomeratic and sandy red beds. Where it reappears from under the alluvium of the Cea valley, near Soto de Valderrueda, the Southern Border Fault has split up into two branches. The northern one runs due east, staying within the Cea sediments. It is impossible to give an exact figure of its throw, but it will probably be in the order of several hundreds of metres at the surface.

The southern branch of the Southern Border Fault runs from Soto to Cegoñal and then through La Espina railway station to Guardo. Two small outcrops of the fault contact are known in the studied area.

The best of these is in the quarry of the tile works of Soto, where "Wealden" clay is extracted. There Cea shale, sandstone and some limestone conglomerate can be seen to overlie the "Wealden" deposits. As the Carboniferous strata lie right-side up, the contact must have the nature of a thrust or a reverse fault. The contact can only be viewed frontally and it is hard to decide whether it is the one or the other, as the dip of the fault plane cannot be determined.

The second outcrop of the southern branch of the Southern Border Fault is about 1 km southeast of La Espina station, along the road to Guardo. Here rather flat-lying, weathered carbonaceous shale of the Cea rests on top of white to pink,

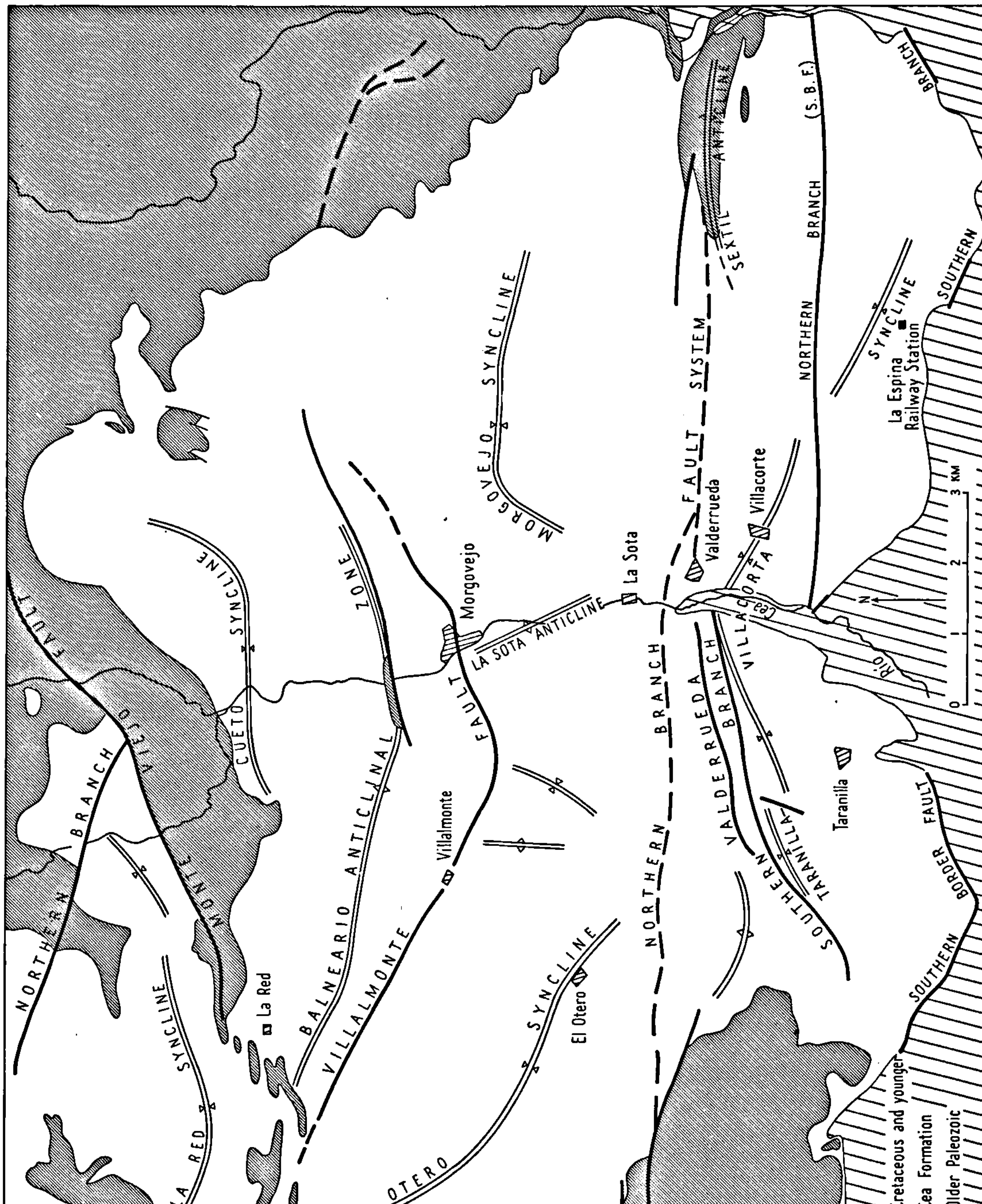


Fig. 22. Structural sketchmap of the Valderrueda basin.

kaolinic sands of the "Wealden". In the outcrop itself it is not clear whether the Cea beds lie right-side up or not. However, the surrounding structural picture makes it improbable that they would be inverted.

2. The Taranilla-Villacorta syncline extends almost over the entire length of the Valderrueda basin. It comprises many smaller structures, folds as well as faults, which have been largely omitted in the map for reasons of scale. The sinuous course of the axis of the Taranilla-Villacorta syncline might be taken to suggest the superposition of a later cross folding on the earlier east-west striking structure. This cross folding involves the Cretaceous near Soto de Valderrueda and does not seem to be related to the original early north-south structures which will be described later. But being a isolated feature which is not repeated anywhere else in the considered area this late cross folding offers no ground for further discussion.

The south flank has been left relatively undisturbed, except for some minor transverse faults and the northern branch of the Southern Border Fault which, however, only features in the eastern half of the syncline. On the other hand the northern flank is strongly disturbed, mostly by east-west striking faults which are all included in the Valderrueda fault system. The deepest part of the Taranilla-Villacorta syncline may be between Taranilla and Prado because there the youngest Cea beds of the Valderrueda basin are found. However, the total Cea stratigraphy is considerably thicker in the east so that the existence of the younger strata in the western part of the syncline does not necessarily mean that in that part the base of the Cea formation lies at greater depth than in the east.

3. The Valderrueda fault system is actually an east-west striking zone in which the Cea strata are severely disturbed. In it tight folding and numerous minor faults occur and steep dips were measured in many places.

The fault system can be traced from the north flank of the Sextíl anticline westward to the north flank of the Peña Corada syncline. Near the Sextíl anticline the system seems to be rather narrow, but near Valderrueda it splits up into two major branches which gradually become more widely separated towards the west. In the east the Valderrueda fault system seems to form the western continuation of a fault in the Older Palaeozoic which was mapped by Koopmans (1962) east of the Carrión river. At its western end the northern branch of de Valderrueda fault system is connected to the large normal fault in the Older Palaeozoic south of the Ocejo basin which, still further west, is continued in the La Llama fault.

The northern branch of the Valderrueda fault system forms a connection between the two above-described faults in the Older Palaeozoic supra-basement, which both have their downthrow to the north. It is therefore logical to assume that this northern branch also has its downthrow to the north even though no conclusive evidence for this could be found in the Cea sediments.

The southern branch of the Valderrueda fault system seems to have the character of a thrust to the south as 1) younger Cea strata occur south of it and 2) in several places where it or its subsidiary faults were observed in outcrops they were thrusts to the south, frequently accompanied by folds with north-dipping axial-planes (see fig. 23).

Thus the area between the northern and southern branches of the Valderrueda fault system seems to form a sort of wedge-shaped horst tapering off towards the east. On the other hand the Sextíl anticline also may be considered to form a horst in the suprabasement which tapers off towards the west. This means that the Valderrueda fault system, if it is taken to include the Sextíl anticline, is underlain by an east-west striking ridge of Older Palaeozoic rocks which is more or less shaped like an elongated hour-glass. The western half of this ridge is formed by the eastern extension of the Peña Corada massif and the eastern half by the Sextíl anticline.

The geological history of the Older Palaeozoic formations (Rupke, 1965) indicates that the rudiments of the Valderrueda fault system may have been present as an eastern extension of the Sabero-Gordón line before the deposition of the Cea formation. Some sedimentary evidence has been found indicating its existence as a ridge in the Older Palaeozoic surface during the deposition of the Cea.

It will be shown later that a great part of the throw of the La Llama fault, which is the western extension of the northern Valderrueda fault, was formed in mid-Tertiary times. It is well possible that this is also the case with the Valderrueda fault system, but no proof for it can be found.

4. The Central syncline actually consists of two synclines with essentially east-west axes, the Otero syncline west of the Cea river and the Morgovejo syncline east of it. The two synclines are separated by an anticline with a north-south axis, the La Sota anticline, which will be described later in this paper.

The axis of the Otero syncline strikes about WNW—ESE and plunges to the southeast, where it is cut off or actually rather "absorbed" by the Valderrueda fault system. The north flank of the syncline is probably most complete (though steeply folded) near Ferreras de la Puerta. Further east the north flank is more affected by the Villalmonte fault. The south flank of the Otero syncline is relatively undisturbed except where it approaches the Valderrueda fault system.

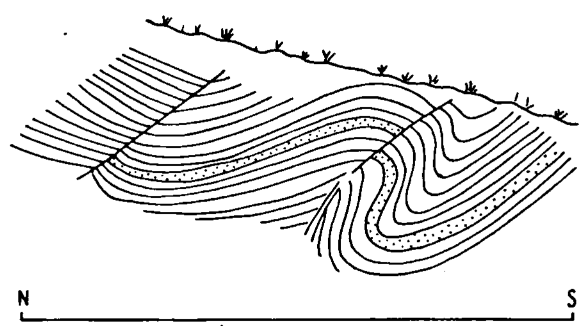


Fig. 23. Subsidiary structures of the southern branch of the Valderrueda fault system (occurring just south of the fault, about 1 km east of Taranilla).

Some cross folding with north-south axes can be discerned in the north flank of the Otero syncline. South of Villalmonte a faint anticlinal bulge and about 1 km east of it a flat syncline were mapped, both with north-south axes.

Further to the east, between Morgovejo and La Sota, the above-mentioned La Sota anticline has developed in what was to be the common north flank of the Otero and Morgovejo synclines. The La Sota anticline has a north-south axis which plunges to the south and which roughly coincides with the course of the Cea river in that stretch. The anticlinal axis is horizontal near Morgovejo but approaching La Sota its plunge becomes ever steeper, which is undoubtedly due to the fact that it approaches the Valderrueda fault system there.

East of the La Sota anticline lies the Morgovejo syncline with an original east-west axis which, however, has been deviated to the south by the La Sota anticline. South of the village of La Sota the axis of the Morgovejo syncline seems to gradually split up into a number of smaller structures in or near the Valderrueda fault system.

Smaller structures have also developed in the lower part of the Cea sequence, east of the divide between the Cea and the Carrión rivers.

The Central syncline is limited to the north by the Villalmonte fault, a structural feature which is distinct in its western part but which becomes less discernible to the east.

5. The Villalmonte fault is probably the one with the clearest surface expression of all the faults in the Valderrueda basin except the Southern Border Fault. It can be traced on the airphotos and in the field between Las Muñecas and Morgovejo. West of Las Muñecas it is much less clear and its existence there was inferred from a few anomalous dip measurements and the outcrop of Older Palaeozoic near Ferreras. It possibly has more the character of a flexure there. East of Morgovejo the Villalmonte fault seems to change gradually into an anticline which occurs in the Carrión deposits to the east. A striking fact is that the Villalmonte fault lies in the westward extension of a fault in the Older Palaeozoic near Velilla del Río Carrión. The Villalmonte fault is undoubtedly directly related to the Balneario anticlinal zone which runs north of and roughly parallel to it.

6. The Balneario anticlinal zone is taken to include two narrow, strongly compressed and faulted synclines which lie on either side of the actual Balneario anticline. About 1 km north of Morgovejo and just north of its Balneario (thermal baths) a patch of Caliza de Montaña (Lower Carboniferous limestone) is exposed in the core of the Balneario anticline. The outcrop is some 800 m long and 100 to 150 m wide and lies on both sides of the Cea river. Along its southern boundary the Caliza de Montaña is thrusted onto Cea shales. This thrust fault probably connects up to the main (normal) fault in the supra-basement. The occurrence of the hot springs at this place lends support to the theory of deep-seated faulting.

The Balneario anticlinal zone extends over some 7 km in an east-west direction. It has at least two culminations separated by a saddle. One of those culminations lies between Ferreras and La Red where Devonian limestone crop out in the core of the anticline. The other culmination is the Balneario anticline proper, in whose core Caliza de Montaña is exposed.

On the map a fault is drawn limiting the Balneario anticlinal zone to the north. This fault is highly conjectural, because the evidence is merely a line of disturbed strata. However, its throw will most probably not be very great.

7. The Cueto syncline forms a conspicuous feature in the landscape of the upper Cea valley because of the resistent quartzite conglomerates of which it is built up. The accessibility in this part of the area is rather difficult due to the steep slopes and the dense bush covering them.

The structure is more complicated than the simple syncline apparent in the first instance. No more than the broad structural lines are given in this study; to unravel the smaller structures in the quartzite conglomerates would require a very detailed investigation.

In the Cueto mountain itself the Las Conjas conglomerates form a single broad syncline, but to the southwest the latter seems to split up into two narrower synclines separated by a dome-shaped structure. In the Las Conjas canyon and west of it the south flank of the main Cueto syncline seems to be folded into several smaller structures, and at least one mappable fault occurs in it. A subsidiary structure in the north flank of the Cueto syncline can be seen from the road when entering the Las Conjas canyon from the south (fig. 24). This splitting up into smaller structures to the southwest is undoubtedly due to the thinning of the quartzite conglomerates in that direction.

West of the Las Conjas canyon the Cueto syncline is developed as a narrow sinuous structure in which the quartzite conglomerates occur in separate lenses and are intercalated with limestone conglomerates, which come in from the west and which were clearly derived from the Devonian and Lower Carboniferous limestones exposed in the surroundings of I a Red.

North of the Cueto syncline the upper Cea valley is underlain mostly by rocks of the Yuso group. Some shales and quartzite conglomerates belonging to the Ruesga Group seem to be exposed along the large east-west Monte Viejo fault between Prioro and the Monte Viejo pass.

8. The La Red syncline actually lies outside the Valderrueda basin proper; it is separated from the latter by a ridge of various Older Palaeozoic rocks and the Monte Viejo fault which will be described below. It is, however, too small to be discussed as a separate basin and as it lies nearer to the Valderrueda basin than to the Tejerina basin, it is described here.

Fig. 24. Subsidiary fold in the quartzite conglomerates of the north flank of the Cueto syncline.

The La Red syncline is a very complete east-west striking structure of about 5 km long and 1 km wide. It is built up of some 200 m of Carrión shales with four to six quartzite conglomerate beds of 2 m to 25 m thickness in its eastern part. To the west the quartzite conglomerates unite and the shales between them wedge out almost entirely. These lower Cea rocks are overlain by about 200 m of Prado shales with limestone conglomerate intercalations. The resistent conglomerate bands make the La Red syncline show up clearly in the aerial photographs.

There is some ground for the assumption that the axis of the La Red syncline plunges again to the northwest after rising above the surface some 2 km northwest of La Red.

Two or three bands of a few metres thickness of quartzite conglomerate and some isolated outcrops of limestone conglomerate occurring stratigraphically above them seem to form a synclinal structure and are in marked discordance with the Yuso strata which surround the syncline.

For this (mainly structural) reason, and in spite of the fact that no fossils nor a distinct unconformable contact were ever found, the above-mentioned conglomerates were tentatively incorporated in the Cea formation. The Cea conglomerates in the north-eastern extension of the La Red syncline are found as far east as the right bank of the Cea river north of Prioro.

This part of the La Red syncline is diagonally crossed by the northern branch of a large fault, the southern branch of which limits the syncline to the south. This main fault, which will be referred to as Monte Viejo fault, probably originated before the deposition of the Cea formation started and may have developed its main activity in that time. In any case it seems to be structurally related to the folding of the Yuso group (section L, app. III) as is also shown by the work of Mr. C. J. T. Bos (intern. rep. Leiden).

The Monte Viejo fault brings rocks of the Ruesga group (Caliza de Montaña) to the surface, which are immediately overlain by Cea quartzite conglomerates north of La Red. This shows that the Yuso rocks had been eroded away in this place when the deposition of the Cea started.

The position of the beds which the Monte Viejo fault displaces and its relation to the structure in general seem to indicate that it is a thrust fault, but it is so badly exposed that it is difficult to be certain.

To the north of the La Red syncline a narrow anticline is developed, the axis of which almost coincides with the bottom of the valley south of the Pico Mentál. In the core of this anticline a limestone band is exposed which has yielded Foraminifera of Moscovian (Mesao Lst.) age (van Ginkel, pers. comm.).

The descriptions of the structures further to the north are incorporated in the structural discussion of the Tejerina basin which follows below.

## THE TEJERINA BASIN

What is considered as the Tejerina basin in this discussion is mainly made up of two synclines which are similar in shape except for the considerable difference in size between them. They are 1, the Mentál syncline and 2, the Tejerina syncline, both of which show up distinctly on the aerial photographs. In fig. 25 a structural sketch-map of the Tejerina basin is given.

1. The Mentál syncline strikes roughly east-west and has a total length of nearly 3000 m; its width is more than 1000 m in the west but it tapers off rapidly to the east. Its axial plane dips to the north as the dips in the south flank range from 35 to 60 degrees and in the north flank from 90 degrees to slightly inverted.

Its lower 150 to 250 m of sediment are Carrión quartzite conglomerates with intercalated shales. The upper 250 m consist of Prado limestone conglomerate with intercalations of shale and a single quartzite conglomerate lens. Both units thin rather rapidly to the east, which explains the eastward-tapered shape of the syncline.

The Mentál syncline has a continuation to the west in the form of a small east-west striking syncline of limestone conglomerate, which is situated on a mountain top that forms part of the divide between the Esla and Cea rivers. This part of the Mentál syncline may be considered as a transition between the Tejerina and the Ocejo basins.

The Mentál and Tejerina synclines are separated by the above-mentioned northern branch of the Monte Viejo fault. The relatively flat-lying south flank of the Tejerina syncline has apparently been thrusted over the vertical north flank of the Mentál syncline. About 100 m of the stratigraphic sequence in the north flank of the Mentál syncline seem to be missing, but the amount of thrust along the considered fault may well be several times greater.

2. The Tejerina syncline is bordered to the north by the Las Salas anticline (Rupke, 1965), which here represents the regionally important León line. It is very similar in shape to the Mentál syncline but it is a much larger structure. Its length is roughly 9 km and it is about 2.8 km wide at its maximum but, like the Mentál syncline, it tapers off towards the west. Again, this particular shape can be explained by the thinning of the Cea sediments to the southeast.

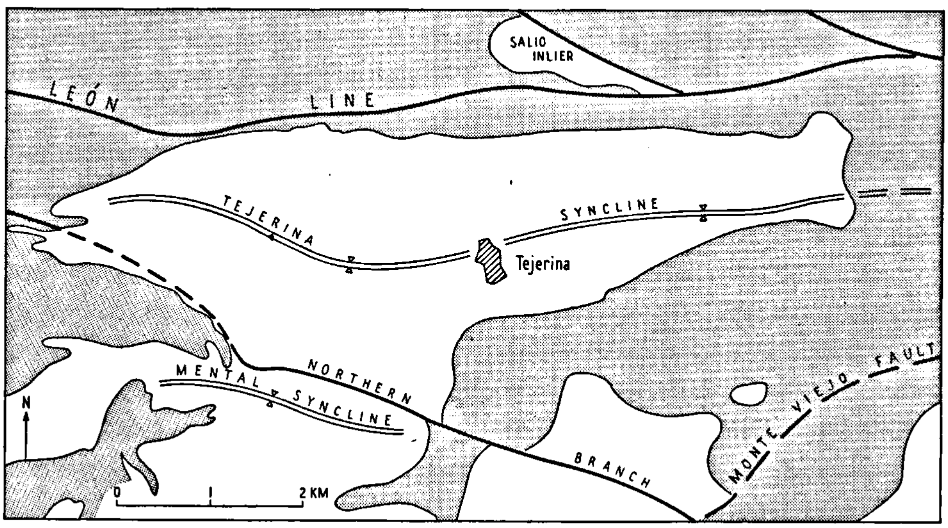


Fig. 25. Structural sketchmap of the Tejerina basin.

The trend of the Tejerina syncline is approximately east-west without any appreciable deviation of its axis. Its north flank is vertical to slightly inverted, and its south flank has normal dips ranging from 50° to 70°. The north flank has a straight linear appearance, but the south flank widens southwest of Tejerina because of a secondary fold which seems to be coincident with a fold in the underlying Yuso beds.

The rapid southward thinning of the conglomerates in the Tejerina syncline indicate that the León line was probably active as a fault in the supra-basement during Cea sedimentation (and even earlier, Rupke, 1965). Thus it may be concluded, that the deformation of the Tejerina syncline already started during the deposition of its sediments. However, the absence of strong intraformational unconformities indicates, that the main part of the deformation took place after the deposition of the Cea formation. In fig. 26 an attempt is made to schematically represent the development of the Tejerina syncline.

North of the Tejerina syncline the only rocks of proved Cea age are found in the Salio inlier, (App. III, sect. L). Here coal-bearing shales and sandstones, which have yielded Cea plants occur in a small patch (its size as indicated on the map is probably considerably exaggerated).

Similar northern occurrences of Cea rocks are known from further west. Some of them will be described by Rupke (1965), while their palaeobotanic aspects are treated by van Amerom (1965). Including the Salio inlier they all lie along and so accentuate a prominent structural line in the regional geology, the León line (de Sitter, 1962a, b).

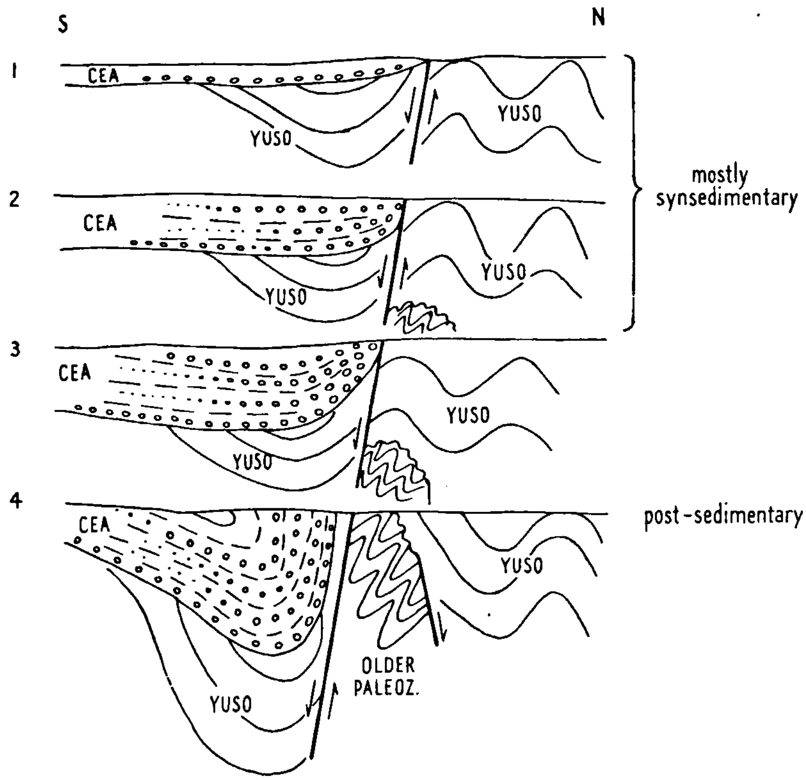


Fig. 26. Schematic representation of the development of the Tejerina syncline.

## THE OCEJO BASIN

In the Ocejo basin two rather complex synclinal structures can be distinguished which lie at almost right angles to each other. Their position is indicated in the structural sketchmap in fig. 27.

The northern syncline has a main axis which strikes about north-south in the south and swings to the east in the north where it merges with the Mentál syncline. This northern syncline will be called the Trapa syncline after a local name for the area comprising the Ocejo valley and its immediate surroundings.

South of the road between Santaolaja and Ocejo lies the southern syncline which will be called the Fuentes syncline. Its axis strikes east-west and joins with that of the Sabero syncline in the west.

There is no sharp dividing line nor any structural high between the two main synclines of the Ocejo basin. They form part of the same structural depression and would normally have been considered as one syncline if they had not shown this striking difference in direction.

The Trapa syncline is considered to extend from the road between Santaolaja and Ocejo in the south to the Mentál syncline (Tejerina basin) in the north. Its axis has a sinuous and undulating character, forming several synclinal depressions separated by saddles.

In the north, near the Tejerina basin, the basal strata of the Trapa syncline still contain some quartzite conglomerate typical for the Carrión member. Further south, however, the Carrión member is represented by a few tens of metres of shale and sandstone with some coal near Ocejo. The Prado member in the Trapa syncline consists of up to a few hundreds of metres of limestone conglomerate with shale and sandstone intercalations.

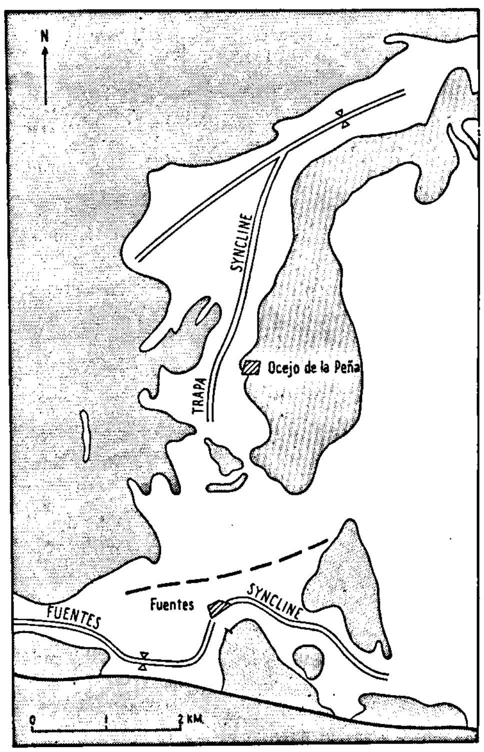


Fig. 27. Structural sketchmap of the Ocejo basin.

The Trapa syncline can be easily recognised on the aerial photographs.

A remarkable fact is that the axis of the Trapa syncline runs roughly parallel with a synclinal axis in the underlying older Palaeozoic. Another fact is that the limestone conglomerates are thickest in the axial part of the Trapa syncline. This leads to the assumption that the Cea formation here was deposited in a topographic depression which was controlled by the pre-existing structures in the supra-basement.

It follows logically that the present Trapa syncline more or less coincides with the original local basin and that its formation was controlled by the original basin form. Then the north-south trend of the Trapa syncline must be considered as the earliest structural trend in the Ocejo basin (and most probably also in the Valderrueda basin).

The Fuentes syncline is an almost monoclinal east-west striking structure. Its south flank is extremely reduced to almost absent because of the combination of southward thinning and faulting occuring in it. The monoclinal impression is further enhanced by the thickening of the north flank by east-west faults. Some secondary folding was also observed in the north flank north and northwest of Fuentes.

The Fuentes syncline is bordered to the south by the western extension of the northern Valderrueda fault which in places has a reverse character. This fault forms part of a fundamental structural line which extends from east of the Valderrueda basin to south of the Sabero basin and further west. Like the León line, this Sabero-Gordón line (Rupke, 1965) is marked by a row of Stephanian coal basins.

## THE SABERO BASIN

Actually the entire Sabero basin comprises only one synclinal structure. This syncline is highly asymmetrical in sedimentary and, partly as a consequence, also in structural respect (sections A to H, App. II). Its structural and sedimentary asymmetry must be mainly attributed to the fact that the Sabero basin, and afterwards its synclinal structure, developed as a result of the gradual growth of a depression or trough along the zone of east-west trending faults which forms the Sabero-Gordón line. The faults have cut away nearly all of the syncline's south flank giving the structure an almost monoclinal aspect. The north flank of the Sabero syncline is relatively undisturbed, in it the dips range from 30° to 90°. A structural sketchmap of the Sabero basin is given in fig. 28.

In the axial part of the syncline secondary vertical and reverse faults show their effect, in the mines (fig. 29) as well as at the surface (Henkes, 1961, p. 56). These faults are frequently accompanied by minor folds. Together these secondary structures are believed to be the manifestation of the activity of large normal faults in the Older Palaeozoic supra-basement in its relatively incompetent Cea cover, as is schematically illustrated in fig. 21. Remnants of the south flank of the Sabero syncline have been preserved in several places between the villages of Sabero and Casetas. Most of those remnants consist of stratigraphically higher parts of the south flank and are in fault contact with Older Palaeozoic rocks. The base i.e. the un-

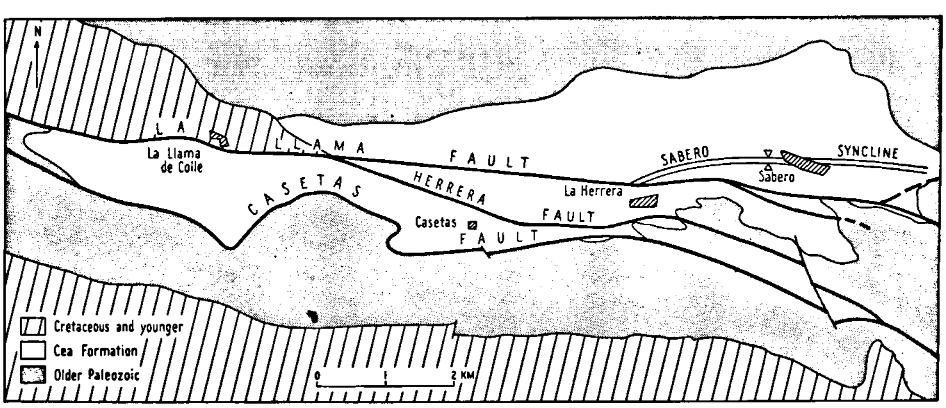


Fig. 28. Structural sketchmap of the Sabero basin.

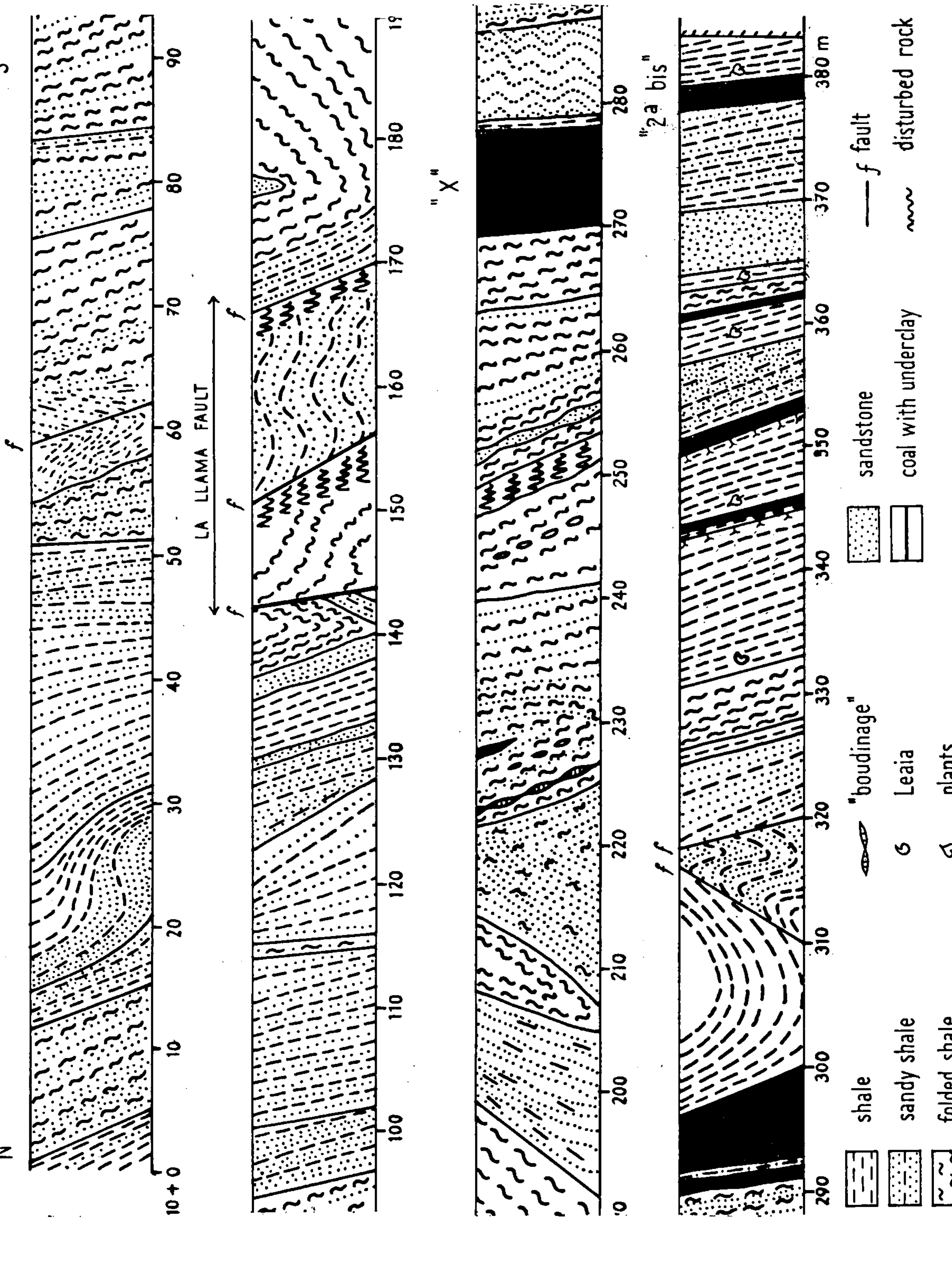


Fig. 29. Section in the cross-cut 3W—7mo Recorte (approx. 180 m below surface) of the Sotillos colliery, showing thrust faults.

conformable contact, of the Cea sediments in the south flank can be observed only in one place, about 1 km south of Sabero, where it lies in a small syncline on the upthrown block of one of the major east-west faults.

The east-west faults in the Cea formation are difficult to trace in the field and more detailed field and subsurface work would be necessary to obtain greater certainty about their accurate position in the map as well as in the cross section. Geophysical methods may provide an image of the shape of the supra-basement surface under the Cea sediments.

Gravimetric work has been started in 1964 by the University of Leiden in the vicinity of the area considered in this paper. However, chances of success by this method seem to be rather remote for the Palaeozoic (including the Cea formation) as the density differences are small. Seismic methods might offer a better possibility of success.

Henkes (1961) recognised several east-west faults in the supra-basement as well as in the Cea formation but he failed to mention their genetic relation. Judging from the schematic cross-section he presents, Henkes (1961, p. 55, fig. 3) attributes the asymmetry of the Sabero syncline exclusively to the sedimentary thinning of the Cea sequence to the south. He also shows the downthrow of the main supra-basement fault as being to the south, exactly opposite to what is put forward in the present paper.

In the Sabero area the Sabero-Gordón line manifests itself mainly in three major faults which are called, from north to south, the La Llama fault, the La Herrera fault and the Casetas fault.

Of these the first one, the La Llama fault, is apparently the most important one. It is the western continuation of the fault bordering the Ocejo basin to the south. Near La Llama this fault has a throw of at least 500 m bringing Upper Cretaceous against Cea rocks (see section A, App. II). Further to the east where it runs within the Cea rocks it is very difficult to trace in the field mainly because of the lack of any apparent stratigraphic markers here. The only indication for its existence in the field is a line of exposures of disturbed strata with steep dips. Only at the eastern end of the Sabero basin, where it crosses the Esla river, the La Llama fault is exposed and there it has the character of a normal fault (Rupke, 1965, p. 56).

As can be seen in fig. 29 several faults were observed in the Sotillos cross-cuts, but with the available data it is impossible to be certain about which of them represents the La Llama fault. Most probably they together make up that feature, the single clear-cut fault in the Older Palaeozoic splitting up into several branches in the overlying Cea sequence with the total throw divided among them.

During the survey of the Sotillos cross-cuts a great similarity in lithology and plant assemblage was observed between the roof shales of two coal beds which are separated by about 600 m of section. In the theoretical case, that these coal beds would in fact be stratigraphic equivalents, the throw of the La Llama fault would at least be some 600 m in the Sotillos area. Of course, more detailed work would have to be done to prove this.

The phenomenon of large normal faults in the Older Palaeozoic supra-basement becoming reverse faults or even thrusts in the Cea sediments draped over them is the same as has been described from the Valderrueda basin. The only difference is that in the Sabero basin all the faults mapped have their downthrow to the north. Apparently the vertical forces active in the rigid supra-basement cause a secondary tangential force in the relatively incompetent sediment cover. The tangential forces originate partly from the covering sediments' own weight and partly from the lateral shortening in the supra-basement as a consequence of rotational block movements along the normal faults.

Fig. 30 offers a schematic representation of the development of the Sabero basin.

In the area considered in the present paper the recurrence of limestone conglomerates in the Prado member indicate that repeated abrupt local uplifts have taken place during Prado deposition. These uplifts were most probably concentrated along the existing east-west faults in the supra-basement, forming scarps which provided the material for the conglomerates. This would mean that these faults were active during the deposition of the Prado member. In the foregoing it has been shown that the same faults also formed the primary factor in the deformation of the

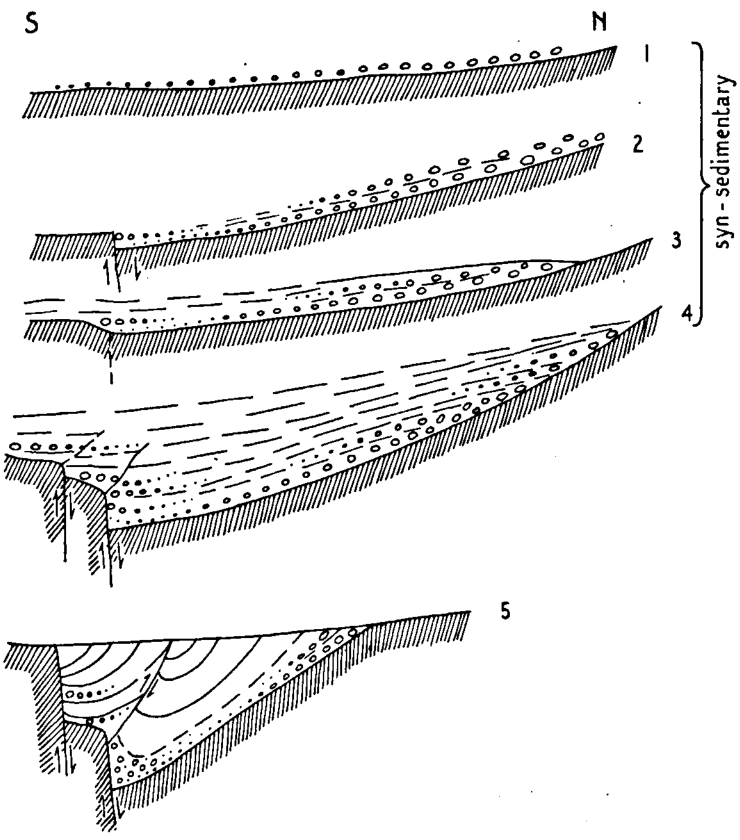


Fig. 30. Schematic representation of the development of the Sabero syncline.

Cea rocks. & Rupke (1965) shows that the fundamental zones to which these faults belong were already active in Devonian times. Consequently there seems to be a reasonable possibility, that the deformation of the Cea formation started during the deposition of the Prado and was thus at least partly "synsedimentary". Synsedimentary deformation has been described, among others, by Pruvost (1939, 1963), Bouroz (1950), Monomakhof (1961) and Zeman (1960).

However, it is unlikely, that this initial deformation in the Cea sediments has been very strong as in that case more or less clear intraformational local unconformities should exist, and none was observed. Most of the deformation of the Cea formation must have occurred after deposition of the entire Cea sequence.

There is a large gap in the post-Cea sedimentary record here which does not permit any conclusions about what happened until well into the Cretaceous. The Cretaceous near La Llama and Las Bodas gives no evidence that the La Llama fault had been active during its sedimentation. Therefore it must be concluded that this fault and other similar ones grew in periods of activity alternating with periods of inactivity, rather than in a continuous process.

The middle Tertiary has been a very important period of activity for the La Llama fault as a great part of its present downthrow developed then.

As the entire deformation of the Cea sediments in the Sabero basin is closely connected to the La Llama and similar faults, a great part of it must also have taken place in mid-Tertiary times.

Of course, the unconformity of the Cretaceous on the Cea near La Llama shows, that the Cea had also been deformed — it was tilted at least 30° south — before the Cretaceous was deposited.

From the foregoing it becomes clear, 1) that both the deposition and the deformation of the Cea formation were closely connected to the east-west faults in the Older Palaeozoic supra-basement, 2) that the deformation has been a long-lasting, intermittent process, probably starting during the sedimentation of the Cea formation and lasting at least into mid-Tertiary times.

CHAPTER III

# GEOLOGICAL HISTORY

It is believed that the main deformation of the Older Palaeozoic of the Leonides, that is the northward thrusting of the Esla nappe and similar structures, took place during the uppermost Namurian and the lower Westphalian (Rupke, 1965).

The crossfolding seen in the Esla area can be related to the same deformation period as the thrusting according to Rupke (1965). Later deformation consisted essentially in general tilting and brittle faulting as a structural adjustment.

The Asturian folding phase (Stille, 1924), which occurred during uppermost Westphalian D and lowermost Stephanian times, is often quoted as a period in which refolding of the Leonide structures took place (de Sitter, 1959, 1961b).

However, there is evidence indicating the probability that the Asturian phase caused folding exclusively in the thick Upper Carboniferous sequence of the Asturides, and that it had a different effect on the Leonide block. This is convincingly demonstrated by the fact that in the few places where typical Asturide (Yuso) sediments occur on the Leonide block, they have been folded in a style different from that of the Asturide structures and more similar to that of the Cea formation, which latter is almost completely restricted to the Leonide block.

Mr. Savage (pers. comm.) brought to the author's attention that north of the León line the Yuso strata are folded into isoclinal structures with well-developed cleavage. Where they occur south of the León line, for instance in the Tejerina-Prioro area, the Yuso folds are similar to and coincident with the structures in the overlying Cea deposits, even though there exists a stratigraphic unconformity between them. Apparently these structures originated from the same mechanism, i.e. the east-west faults in the underlying Older Palaeozoic rocks. It also seems probable that the Yuso rocks had only suffered the same degree of lithification as the Cea.

Presumably the Leonide block was being uplifted during the entire Westphalian epoch and formed the main source of sediment for the subsiding Asturian basin.

At the end of the Westphalian the process was (partly) reversed, possibly as a result of isostatic compensation, and the Leonide block subsided somewhat in relation to the Asturian block. In the Asturian basin sedimentation came to a halt and folding, uplift and erosion followed each other in relatively quick succession (Asturian phase of orogeny).

The Tejerina-Prioro area formed one of the exceptionally low parts of the Leonide block since it is one of the two places known where Yuso sedimentation extended south of the León line (Rupke, 1965, p. 41). This sedimentation, in the Tejerina-Prioro area, was limited to the west by a high corresponding to the Esla nappe.

Near the end of the Westphalian the sedimentation must at least have been interrupted, in view of the unconformity between the Yuso and the overlying Cea formations. However, the topography at the commencement of the deposition of the Cea had altered very little. Subsequently sedimentation became more general, gradually filling up depressions and transgressing onto higher parts.

Main regional movement during Cea deposition can be split into two components: 1) a general tilt to the southeast, and 2) differential subsidence between several elongated, east-west trending blocks south of the León line as a structural adjustment.

Evidence for the general tilt is found in the southward increase of marine influence in the Cea formation, showing that the largest amount of subsidence took place in the south.

The differential subsidence between blocks can be inferred from the sedimentary and structural configuration of the Cea formation.

Except for the above-mentioned Asturide and Leonide blocks, it is also possible to speak of a Duero block which more or less comprises the present Duero basin. This Duero block is separated from the Leonide block by a ridge of Older Palaeozoic rocks which is bounded to the south by the southern border flexure (Southern Border Fault in the Valderrueda basin) of the Cantabrian mountain range and to the north by the Sabero-Gordón line. Rupke (1965) has demonstrated that the Sabero-Gordón line is a fundamental feature which already exerted its influence on the sedimentary pattern in the Devonian.

Sedimentary evidence in the Cea formation shows that the Sabero-Gordón line was also active during the deposition of the Cea. The above-mentioned Older Palaeozoic ridge south of that line formed a narrow east-west trending topographic barrier along the southern boundary of the Leonide block.

During the deposition of the Carrión member the Leonide block was only submerged as far as a line running from Huelde to the southeast. The westernmost occurrence of marine influence in Carrión rocks is found in the Sextíl anticline, north of La Espina. Fig. 31 represents a lithofacies map of the Carrión member.

At the end of the Westphalian there probably was a rapid rejuvenation of relief during which limestone formations were exposed in the north and east. This was immediately followed by the deposition of the Prado member which is characterised by its limestone conglomerates.

During Prado deposition there were times during which the sea penetrated as far west as El Otero and Villalmonte in the Valderrueda basin.

The sediments gradually overlapped the eroded surface in a western direction and the fault trough which had formed north of the Sabero-Gordón line was filled as the subsidence along this fault proceeded. The transgressive nature of the Prado member in this fault trough is clearly shown by the fact that, going from east to west, ever-younger sediments are found in it.

The same tendency is shown along the León line. The basins along this line contain older deposits in the east (Tejerina basin) than in the west (Salamón-Viego and other basins). Here the Cea sedimentation started somewhat later than along the Sabero-Gordón line because the northern part of the region remained high longer than the southern part. A lithofacies map of the Prado member is given in fig. 33.

Considering the given facts the author is tempted to believe that the centre of uplift during Cea deposition was situated to the northwest and the centre of subsidence to the southeast of the studied areas.

The centre of uplift (isostatic compensation?) may have coincided with the Central Asturian basin where the thickest Westphalian section is found.

The centre of subsidence would then have been on the eastern part of the Duero block, in the direction of which also an increase of marine influence has been noted.

An attempt is made in figs. 32 and 34 to represent the palaeogeographic development of the Cea formation in the investigated area.

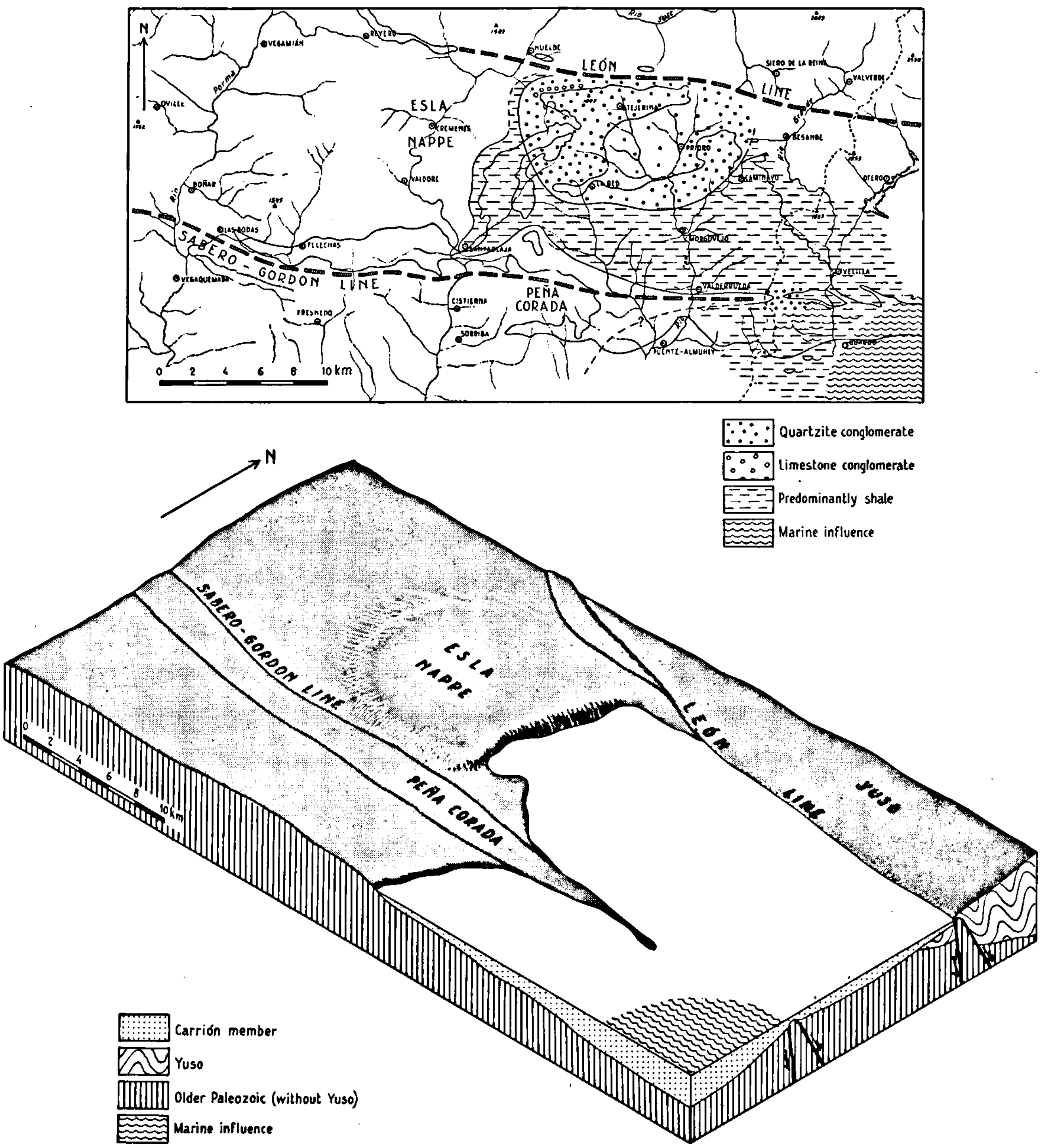


Fig. 31—32. Lithofacies map and inferred palaeogeographic diagram for the Carrión member.

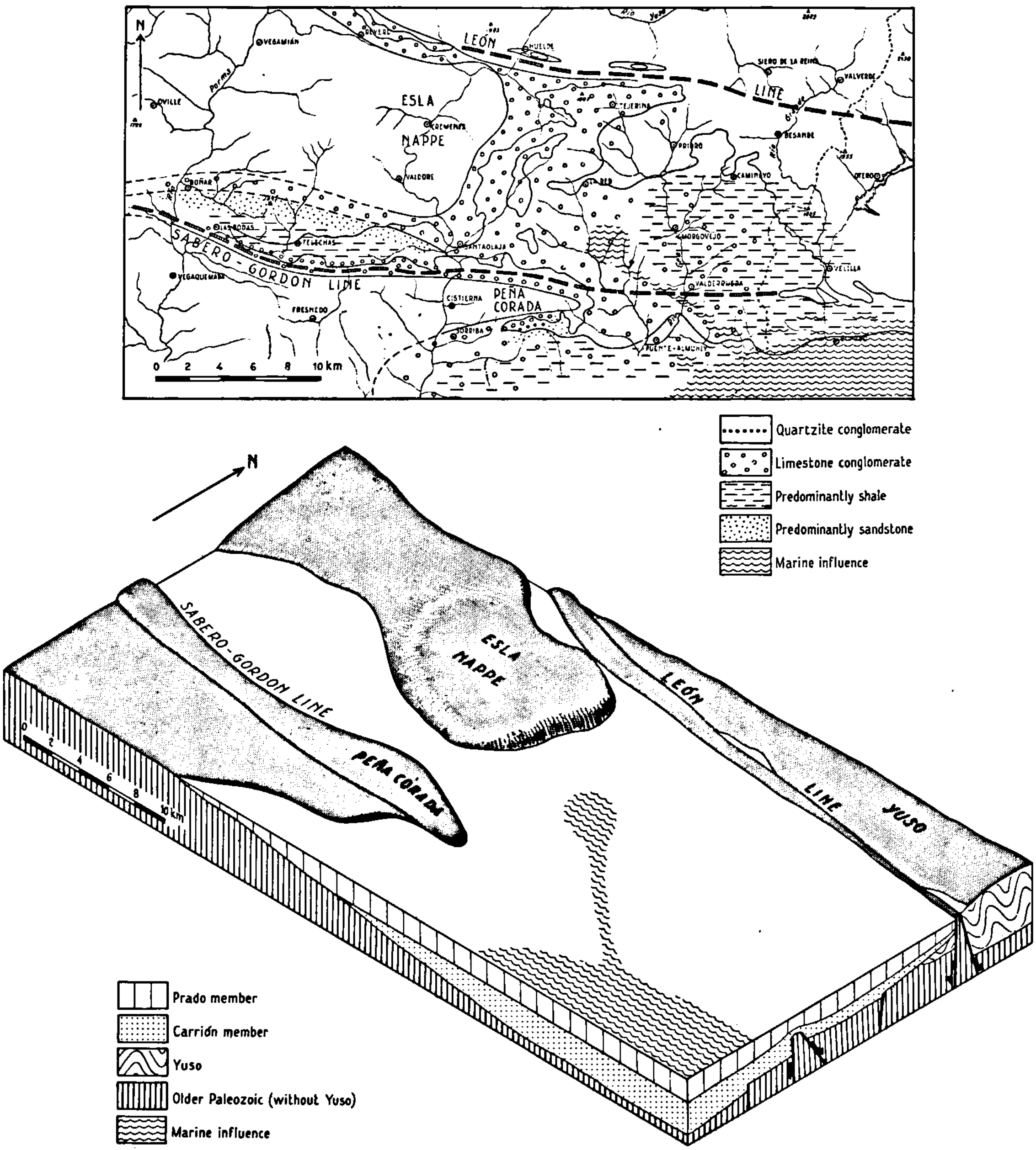


Fig. 33—34. Lithofacies map and inferred palaeogeographic diagram for the Prado member.

The deformation of the Cea formation was apparently controlled by the same faults or fault zones which were such important controlling factors during its deposition.

It is probable that some deformation of the Cea rocks already took place during its deposition, apart from the structures purely resulting from differential compaction.

However, no intraformational unconformities, which would point to strong synsedimentary deformation, were observed in the Cea formation. The larger part of its deformation must have occurred after the deposition of the Cea.

Due to the complete absence of pre-Cretaceous Mesozoic sediments in this area it is impossible to date the Cea deformation with any accuracy.

From the angle of unconformity between the "Wealden" and the Cea near La Llama de Colle it follows that the Cea strata have been dipping at least 30 degrees south when the "Wealden" was deposited (a similar observation was made by Quiring (1939) near Cervera de Pisuerga). This indicates that the La Llama fault had been active in the time-lapse between the Stephanian A—B and the Upper Cretaceous.

However, the Cea strata there now dip at about 70 degrees south so that a great part of the deformation must have occurred after the deposition of the Cretaceous. Indeed it is seen near Las Bodas that the Upper Cretaceous and Lower Tertiary have been involved in the activity of the La Llama fault, showing that this fault was active again during middle Tertiary times.

The deformation of the Cea formation has apparently been a long-lasting intermittent process, which occurred in three stages: 1. a synsedimentary stage, 2. a post-Stephanian and pre-Cretaceous stage and 3. a middle Tertiary stage.

Obviously the old idea, i.e. that the Cea formation had been folded in a Permian (Saalic) tangential compressive phase, must be abandoned.

## RESUMEN EN ESPAÑOL

Las cuencas hulleras que han sido el objeto de este estudio están situadas por la mayor parte en el rincón noreste de la provincia de León. Solo el extremo este, junto a la riva derecha del Río Carrión, forma parte de la provincia de Palencia.

La formación hullera que constituye el relleno de las cuencas de Valderrueda (incluso la parte de Guardo), Tejerina, Ocejo y Sabero ha sido llamado la formación del Cea, según el Río Cea que pasa por el medio de la cuenca de Valderrueda, la mas grande de las cuatro cuencas estudiadas.

Dentro de la formación del Cea se han distinguido los dos miembros siguientes.

1. El miembro del Carrión, siendo la parte inferior, consiste de conglomerados de cantos de cuarzita, areniscas, pizarras y capas de antracita. Este miembro inferior tiene un espesor máximo de unos 1200 m en su localidad tipo,al borde derecho del Rio Carrión entre Guardo y Velilla del Río Carrión. Pero su espesor diminuye rápidamente hacia el oeste pués en la parte occidental de la cuenca de Valderrueda queda reducido a unos pocos metros. También existe una transición lateral de facies en el miembro del Carrión. En su localidad tipo consiste de un lente de conglomerado de cuarzita de unos 25 m de espesor a su base, y por lo demás de pizarra, arenisca y capas de antracita. En la cuenca de Tejerina está formado de conglomerado de cantos de cuarzita con lentes de cantos de caliza y intercalaciones de pizarra. En la cuenca de Ocejo el miembro del Carrión consiste de unos 60 m de pizarras y areniscas con lentes de carbón y un banco de arenisca cuarzitosa muy dura. En la cuenca de Sabero el miembro del Carrión está representado solo en el rincón noreste, cerca de la aldea de Alejico.

Los fósiles vegetales indican que el miembro del Carrión es de edad Westfaliense D, con excepción de su extremo occidental, en la cuenca de Sabero, donde pertenece al Estefaniense A. La diminución del espesor y el carácter diácrono del miembro del Carrión demuestra que es una serie transgresiva hacia el Oeste.

2. La parte superior de la formación hullera ha sido llamado el miembro de Prado come tiene su localidad tipo en las concesiones de Hulleras de Prado, S.A. En realidad el corte tipo no representa más que la parte inferior del miembro de Prado. La parte superior se enceuntra en la cuenca de Sabero. En el corte de Prado el espesor máximo es aproximadamente 1000 m, y en el corte de Sabero unos 1500 m. Juntando estos cortes, el espesor máximo del miembro de Prado sería unos 2500 m. Sin embargo, en la región cantábrica no se conoce ninguna localidad donde existe la sequencia completa del miembro de Prado.

Litológicamente el miembro de Prado muestra algunas diferencias concretas de lo del Carrión. El miembro superior consiste de pizarras y areniscas con bancos de conglomerado de cantos de caliza y capas de carbón seco o graso.

En su localidad tipo, en la cuenca de Valderrueda (y también en la de Tejerina), el miembro de Prado pertenece al Estefaniense A mas bien inferior hasta intermedio, mientras que en la cuenca de Sabero es de edad Estefaniense A intermedio y superior, possiblemente alcanzando hasta al Estefaniense B en su tramo superior. La ausencia de los estratos inferiores en la parte occidental de la región se explica por el carácter transgresivo de la formación del Cea.

La estructura de la formación hullera está dominada por sinclinales asimétricas, anchas, separadas por zonas distorbadas, estrechas, en que afloran rocas mas antiguas (infra-Carboníferas, Devonianas, etc.) en algunos sitios. Este tipo de estructura sugiere que el Paleozóico debajo de la formación hullera está dividido en bloques por fallas normales, largas, de rumbo este-oeste. El movimiento relativo, esencialmente en sentido vertical, entre estos bloques ha sido la causa principal del plegamiento de la formación hullera superpuesta.

Se ha demostrado que algunas de las fallas en el Paleozóico mas antiguo han sido activas intermitentemente durante un período del Devoniano hasta el Terciario intermedio. Por consequencia los plieges de la formación hullera, siendo dependientes de estas fallas, se han desarrollado durante un período muy largo.

Parece que el idea antigua, que la formación del Cea hubiera sido plegado en una fase orogénica Permiana (Saalica) de duración corta, debe ser abandonado para la región cantábrica.

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