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GEOLOGY OF THE LEONIDES BETWEEN THE BERNESGA AND PORMA RIVERS, CANTABRIAN MOUNTAINS, NW SPAIN

BY

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ABSTRACT

A stratigraphic analysis of the Lower Palaeozoic in the Bernesga-Porma area revealed relatively stable shelf conditions in the miogeosynclinal part of a geosyncline located further to the south (fig. 5). The Caledonian period might be represented by the synsedimentary volcanism (dolerites and tuffites) during the Ordovician and Silurian. With the onset of the Devonian, the shelf area became progressively less stable and is separated into the Bernesga and Esla sub-basins by the WSW-ENE trending Pardomino ridge (fig. 15). The Leonide facies south of the León line varies in composition and becomes thinner towards this line (fig. 14 and app. III and IV). The WNW-ENE trending Sabero-Gordón hinge line becomes apparent during the Upper Devonian; it separates an area of progressively steeper uplift and subsequent erosion in the northern Leonides from an area of continued subsidence and rapid sedimentation in the southern Alba and Corada sub-basins (fig. 16). The fundamental León, Sabero-Gordón and Pardomino lines were reactivated during the Lower Carboniferous (fig. 23) which is identified by shallow marine, condensed sequences and again during the deposition of the Upper Carboniferous flysch and molasse facies in tectonically controlled asymmetric basins (figs. 30 and 66).

The Bretonic epeirogenic phase resulted in a ± 4° SSW tilt of the Leonides west of the Pardomino line (fig. 14) and further accentuated the outwedging of the strata. The geometry of the asymmetric folding and thrusting of the Leonides during the initial Sudetic folding phase is a direct consequence of the palaeogeography and facies boundaries recorded (fig. 63). Subsequent erosion of these culminations produced the coarse-grained material of the flysch facies, consisting of graded wackes and turbidites (fig. 65). The gradually climaxing Asturian folding phase migrated in time and space; the oldest tecto-facies are developed on top of the Visean Alba griottes south of the Sabero-Gordón line, while north of this line they are found on top of the Namurian (A) Caliza de Montaña Formation (fig. 31). The youngest fusulinid assemblages in the San Emiliano Formation south of the León line indicate the base of the Westphalian, while the youngest fossil determinations in the Lena Formation north of this line are indicative of the Upper Westphalian (app. V). The depositional environment changes from marine to paralic and finally to continental.

In the Bernesga-Porma area, the Leonides consist of seven thrust units, which are more than 25 km long and approximately 2 km thick; the maximal recorded displacement is more than 3 km. These thrust units were back-folded and faulted before they were partly covered by Stephanian molasse facies, deposited in intramountainous basins in the back- and fore-deeps of the thrust-folds. In the disharmonically folded Piedrafita Unit parasitic and cascade folds occur (figs. 70 and 71); stretching of the competent beds (boudinage) and flattening of argillaceous beds (slaty cleavage) were also recorded (fig. 60). The Stephanian Matallana and Rucayo basins are mainly deformed by reversed faulting in the basement (fig. 72) during and after the molasse deposition (late-orogenic Saalic phase). Epithermal mineralizations and silicious mylonite lenses mark the most important fault zones.

The large gap in the stratigraphic record (Stephanian-Upper Cretaceous) represents the period of structural adjustment and uplift of the Hercynian core of the Cantabrian Mountains. After the Upper Cretaceous transgression had ceased (fig. 39), a strong morphogenetic uplift (> 1 km) related to the Savian phase (Oligocene) took place along a narrow E-W trending flexure zone (fig. 76). The extensive erosion resulted in the deposition of limestone conglomerates in torrential piedmont fans towards the down-warped León Basin (fig. 74). The geometry of the associated mountain flank thrusting was also studied from detailed gravity profiles covering the entire area (fig. 75). The tectono-stratigraphical evolution of the Bernesga-Porma area is sketched in figure 77.

RESUMEN

El análisis estratigráfico del Paleozóico Inferior en el área Bernesga-Porma revela condiciones de un escudo relativamente estable en la parte miogeosinclinal de un geosinclinal que continúa hacia el Sur (fig. 5). El vulcanismo sinsedimentario durante el Ordoviciense y Silúrico (doleritas y tobas) podria representar el período Caledónico. A partir del Devónico, el área de escudo progresivamente llega a ser menos estable y está separado en las sub-cuencas Bernesga y Esla por la cresta de Pardomino con dirección OSO-ENE (fig. 15). Al Sur de la linea tectónica de León se encuentra la facies Leonidiense la cual varía en composición y se vuelve más delgada hacia el Norte (fig. 14, app. III y IV). La linea de charnela Sabero-Gordón, se manifiesta por la primera vez en el Devónico Superior. Ella separa un área de levantamientos progresivamente más empinados con erosión subsecuente hacia el Norte, de un área de continua subsidencia y rápida sedimentación en las sub-cuencas Alba y Corada al Sur de esta linea (fig. 16). Las lineas fundamentales de León, Sabero-Gordón y Pardomino fueron repetidamente reactivadas durante el Carbonífero. El Carbonífero Inferior esta caracterizado por secuencias marinas poco profundas y el Carbonífero Superior por facies flysch y molasa en cuencas asimétricas tectonicamente controladas (figs. 30 y 66).

La fase epeirogenética Bretónica dió como resultado un basculamiento SSO de más o menos 4° en el área al oeste de la linea Pardomino (fig. 14); el hiato subsecuente ha acentuado el acuñamiento de los estratos. La geometria de los plegamientos asimétricos y de los cabalgamientos durante el período inicial del plegamiento Sudético es una consequencia directa de la palaeo-

geografía y de los límites de facies (fig. 63). Los cabalgamientos fueron dirigidos desde las áreas de mayor subsidiencia al Sur de la linea Sabero-Gordón hacia las crestas de León y Pardomino (fig. 66). Estas fallas de levantamiento proporcionan cuencas marginales rellenadas con facies de flysch con grauvacas clasificadas y turbiditas (fig. 65). La fase de plegamiento Asturiano gradualmente adquirió su climax y migró en tiempo y espacio. Esto se nota por las facies tectónicas; el flysch más antiguo se desarolla sobre la parte superior de la Formáción Alba (Viseense) al Sur de la linea Sabero-Gordón y al Norte de esta linea, el flysch se encuentra sobre las calizas Namurienses (fig. 31). Los fusulinides más jóvenes de la Formación San Emiliano (al Sur de la linea León) indican la base del Westfaliense, mientras que los fusulinides más jovenes en la Formación Lena (al Norte de dicha linea) indican el Westfaliense Superior (app. V). El ambiente deposicional del flysch cambia de marino a parálico y finalmente a continental.

En el área Bernesga-Porma, se reconocieron por lo menos siete unidades de cabalgamiento de más de 25 km de largo con un espesor aproximado de 2 km y un desplazamiento máximo de 3 km. Estas unidades fueron replegadas y falladas antes que la facies de molasa (Estefaniense) los cubiera en cuencas intermontañosas (fig. 66). En la unidad Piedrafita ocurren plegamientos parasíticos y de cascada (figs. 70 y 71), localemente acompañados de estiramiento de los estratos competentes (boudinage) y aplanamiento de las capas argilaceas (clivaje pizarroso) (fig. 60). Las cuencas hulleras de Matallana y de Rucayo están deformadas principalmente en relación con fallamiento inverso del basamiento (fig. 72) durante y después de la deposición de molasa (la fase post-tectónica Saálica). Mineralizaciones locales y lentes miloníticos marcan las zonas importantes de falla.

El período de ajustamiento estructural y levantamiento del núcleo de la Cordillera Cantábrica, se manifiesta en el hiato entre el Estefaniense y el Cretácico Superior. Después que la transgresión del Cretácico Superior (fig. 39) cesó, un levantamiento morfogenético ocurió durante el Terciario Inferior, a lo largo de una estrecha zona de flexiones con direcion E-O, relacionado con la fase Savaniense (fig. 74). Abanicos aluviales de piedemonte, compuestos principalmente de conglomerados de caliza, se depositaron rapidamente en la cuenca de León. Con perfiles detallados de gravedad (fig. 76) se estudió también la geometría de los cabalgamientos en el flanco montañoso. La evolución de las estructuras en el área Bernesga-Porma se presenta en forma esquemática en la figura 77.

CONTENTS

Appendices
  I. Geological map
  II. Cross-sections
  III. Columnar sections of the Lower Palaeozoic and Devonian
  IV. Columnar sections of the Lower Palaeozoic and Devonian
  V. Columnar sections of the Upper Carboniferous
  VI. Fold-model

INTRODUCTION

In 1950, the Department of Geology of the Leiden University in Holland started a geological study of the southern slope of the Cantabrian Mountains in the northern part of the province of Palencia. Reconnaissance work eventually led to the adjacent provinces of León, Asturias and Santander. A provisional map (1 : 100 000) of the area between the Pisuerga and Luna rivers was published by de Sitter in 1962.

Meanwhile, the decision was made to start a systematic program of detailed mapping at a scale of 1 : 50 000 by graduate students from the Department of Structural Geology. Prof. Dr. L. U. de Sitter and Dr. D. Boschma (1966) described the sheet "Pisuerga"; J. Rupke (1965) and B. Helmig (1965) the sheet "Porma-Esla-Cea" and N. Sjerp (1967) the sheet "San Isidro-Porma". As shown on the structural index map, these sheets are situated to the north and east of the area to be considered in this paper.

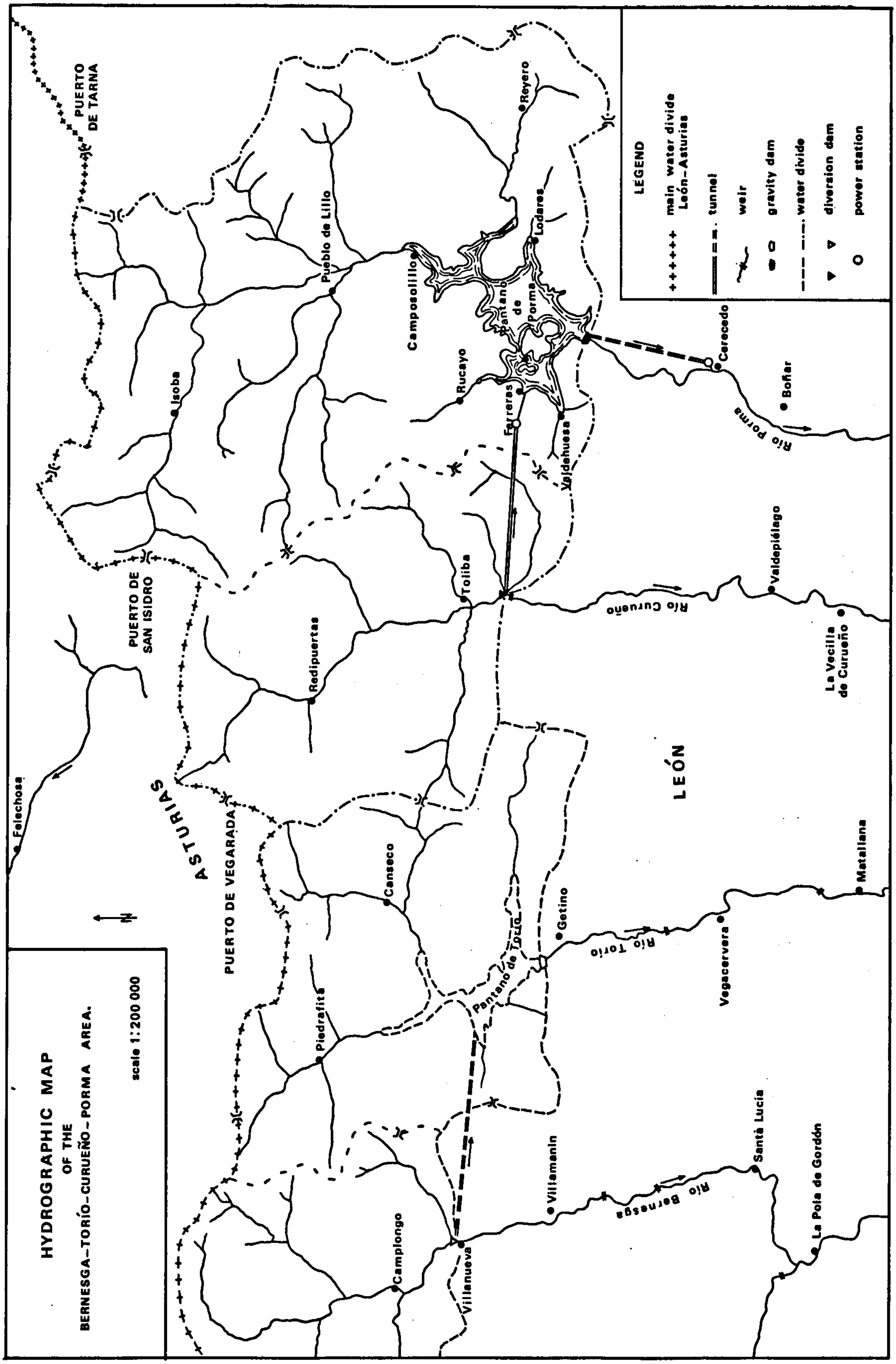

Fig. 1. Existing and proposed (dotted lines) hydrological projects in the Bernesga-Porma area.

Many Spanish, French and German geologists studied the Cantabrian Mountains, mainly in relation to the rich fossil localities or mineral resources: for instance, Casiano de Prado (1850), de Verneuil (1850), Barrios (1879—1882), Mallada (1886—1927), Delépine (1943), Ciry (1939—1963), Almela (1949), Lotze & Sdzuy (1961), Wagner (1963—1966) and many others. Special attention is directed to the study of the Luna-Esla area by Comte (1959), who described the stratigraphy and palaeontology of the Palaeozoic rocks in general and the Devonian units in particular.

The present paper describes the geological history of the sheet "Bernesga-Torío-Curueño-Porma". The geological map with cross-sections and columnar sections is located in the back of this volume.

Geographic Position

The geographical limitations of the present sheet are: latitude — 42°47′33″ to 43°00′27″ North and longitude — 1°36′00″ to 1°59′00″ West of Madrid, which corresponds to 5°18′ and 5°41′ West of Greenwich.

Between 1961 and 1965, field work was carried out on topographic maps with scales of 1 : 25 000 and 1 : 10 000; these were enlarged from the detailed topographic maps (1 : 50 000) of the Instituto Geográfico y Catastral, Madrid, using the following sheets: 78 (La Pola de Lena), 79 (Pueblo de Lillo), 103 (La Pola de Gordón), 104 (Boñar), 129 (La Robla), 130 (Vegas del Condado). Some aerial photogrammetric corrections had to be made in the topographic base of the geological map.

Aerial photographs

The aerial photographs were placed at our disposal by the courtesy of the Instituto Geológico y Minero de España. The numbers of the runs covering the present map are: 43721—43735, 43510—43524, 43331—43318, 43174—43185, 52975—52976, 20351—20344 and 13587—13581.

The mean scale of the aerial photographs was approximately 1 : 37 500, while field mapping was carried out on a scale of 1 : 25 000. These high-quality photograps were very suitable for the geological survey because: 1. the relief is pronounced, 2. vegetation is scarce, 3. the difference in resistance to weathering between the rock formations is great, 4. folding is purely concentric in the Leonides, 5. the layers often dip sharply.

Hydrological remarks

The main rivers run perpendicular to the E-W trending structures of the Cantabrian Mountains in which steep canyons have been formed. The tributary rivers are parallel to the main trend and mainly restricted to the less resistant rock units. The Bernesga, Torío, Curueño and Porma rivers belong to the Duero drainage area, which runs through the Meseta of Old Castille to the Atlantic Ocean. During the dry summers, wheat and grass can be cultivated only by irrigation in extensive draining systems. Nearly all the water available for irrigation is thus consumed in the narrow valleys of the upper reaches of these rivers. Recently however, several pressure dams for storing great quantities of water have been built and many more are planned by the Confederation Hydrologica del Duero for the irrigation of the "Tierra de Campos" on the meseta of León, which is the only flat area where agriculture can be mechanised (fig. 1).

The resistant orthoquartzites of the Barrios Formation will be used as foundation for the Torío Dam just north of Getino. In the Bernesga Valley there are many good

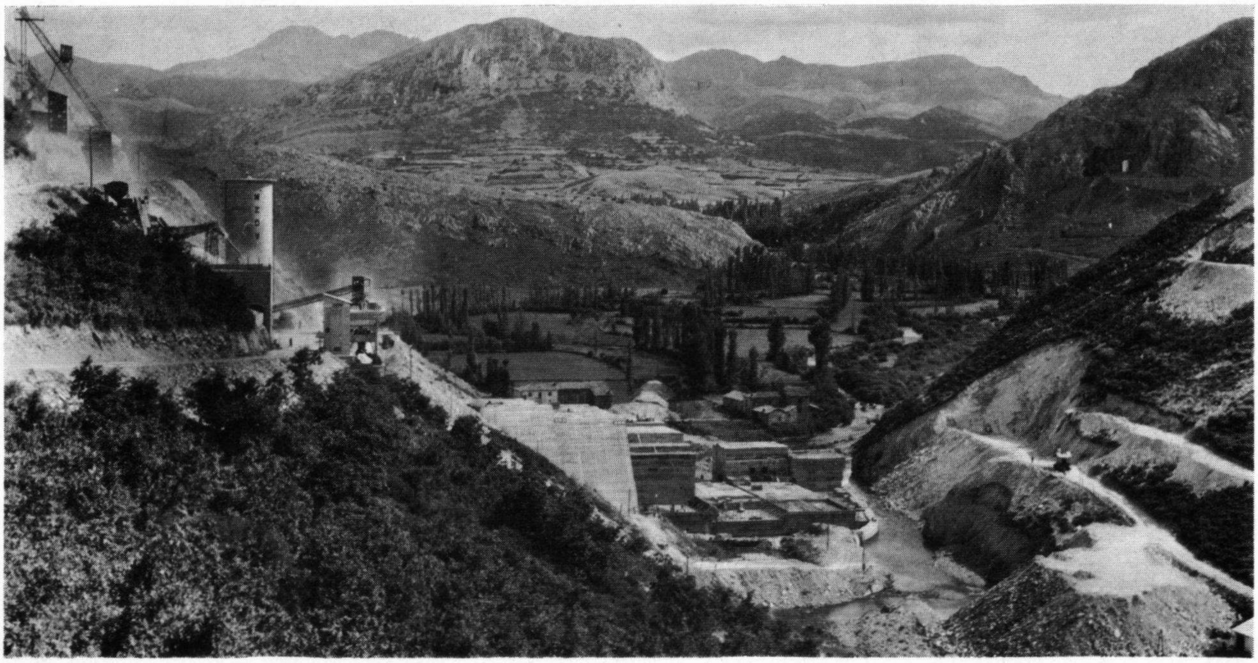

Fig. 2. The Porma dam site south of Vegamián; built on quartzites of the Herreria Formation.

dam sites, but since the main traffic arteries to the Pajares Pass and Asturias run through this valley, it was decided to divert the headwaters of the Bernesga River and thus enlarge the catchment area of the Torío Lake. Since the downstream irrigation area of the Torío Valley is relatively small, the water of this lake will also be used for the rapidly growing demands of the capital of León.

The gravity dam (fig. 2) in the Porma River south of Vegamián is built in the quartzitic sandstones of the Herreria Formation. A tunnel diverts the headwaters of the Curueño River to the Porma Lake; power stations will be built at Ferreras and Cerecedo.

Another project that will result in greater water storage in the mountains and also reduce further erosion is the use of pines to reforest barren mountain slopes by the "Patremonio Forestal del Ministerio de Agricultura."

Mining

Coal mining has been intensive in the major Matallana-Ciñera Basin and in the less important Rucayo and Piedrafita basins, but after the war many smaller mines had to be closed. The locally thick coal seams consist mainly of fine-grained fat-coal ("hulla"). The La Providencia and La Profunda mines NW of Carmenes were the most productive ore mines in the present area; they yielded copper, nickel, cobalt and iron. Other mines produced lead, zinc, manganese and to a lesser extent mercury and barite.

Weathering

a. Mechanical weathering is considerable due to:

1. Important temperature difference between day and night (> 30°C).
2. Occasional high precipitation and little vegetation.
3. Steeply dipping strata with large differences in resistance to weathering (Solé Sabaris *et al.*, 1952).

The massive limestone ridges have the most pronounced relief, while the resistant orthoquartzites form smooth ridges flanked by extensive screes (see map and fig. 3).

b. Chemical weathering is active in most limestones; large karst areas are located around the Hoces de Vegacervera and in the Sierras de Sancena. Of the many cave systems explored, the nearly 2 km long caves of Valporquero de Torío are famous for their diversified beauty.

Acknowledgments

In the right-hand corner of the geological map, an index map shows the areas initially surveyed by the students listed. Winkler Prins also made a special study of the igneous rocks exposed in the present area.

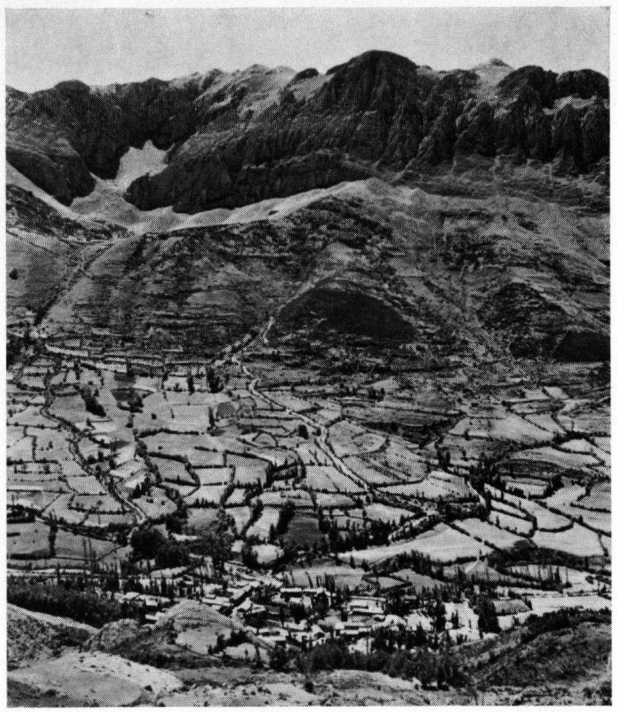

Fig. 3. Large screes and specific weathering of the Barrios and Caliza de Montaña Formations, S. of Genicera.

I am very grateful for their observations which form the "basement" for this regional geological study.

I am also grateful for the fossil determinations made by my colleagues from the Geology Department, especially Dr. A. C. van Ginkel (fusulinids). The fossils and thin sections can be found in the collection of the *Rijksmuseum voor Geologie en Mineralogie, Leiden.* The plant fossils were determined by Van Amerom and are now in the collection of the *Geologisch Bureau voor het Nederlands Mijngebied, Heerlen.*

I wish to express my sincere thanks to Professor Dr. L. U. de Sitter who supervised my graduate work in a most stimulating and pleasant manner, and to Dr. D. Boschma, Dr. A. C. van Ginkel and Dr. J. Savage for their kind assistance. The skillful technical help received from Miss Cor Roest and Mr. F. J. Fritz (for drawings), Misses Hanny Oosterom and Tine Terpstra (typing), Mr. Hoogedoorn (photographs) and Mr. Van Leeuwen and Mr. Schipper (for thin sections) is greatly appreciated. Mr. Alberto Alvarez — Osejo was so kind to translate the summary into spanish.

I am especially grateful to Professor Dr. J. G. Hagedoorn and other staff members of the Department of Geophysics and Hydrogeology for so many years of pleasant collaboration under such unforgettable "bright skies".

CHAPTER I

STRATIGRAPHY

INTRODUCTION

In the Cantabrian Mountains, a Precambrian to Quaternary succession can be studied which includes several regional and local unconformities and stratigrafic gaps. In the Palaeozoic rocks of the present area between the Bernesga and Porma rivers, three sedimentary rock associations are noticed.

1. The orthoquartzite — carbonate association, or stable shelf (litho-)facies (Pettijohn, 1957, p. 611) in recognition of the structural stability of the site of deposition; roughly during the Cambro-Silurian, Devonian and Lower Carboniferous. Especially the younger formations are relatively thin and show many breaks in the faunal and lithologic sequences. The calcareous and quartzitic sandstones generally consist of well-rounded, mature quartz grains; cross-bedding and ripple marking are common. These shallow water facies rest unconformably on a (stable) Precambrian basement.
2. The greywacke association, or orogenic flysch (litho-) facies to emphasize the tectonic environment of deposition during the Namurian and Westphalian. The flysch facies in the paralic marginal basins are marked by their great thickness and argillaceous character. Slumped bedding and convolute folding occur frequently in these graded wacke assemblages. The lenticular limestone beds decrease towards the coarser top of the flysch facies, where coal beds intercalating with thick-bedded subgreywackes mark the gradual transition of the molasse facies.
3. The subgreywacke association, or late-orogenic molasse (litho-)facies consisting of "coal measures" of roughly Stephanian age. The immature products of denudation, consisting of conglomerates, coarse-grained subgreywackes with rock fragments and carbonaceous mudstones, were deposited in unstable intramountainous basins.

Mesozoic rocks are absent in the present area until the transgressive Upper Cretaceous, which is paraconformably overlain by coarse-grained terrestrial deposits. These reddish molasse facies mark the morphogenetic uplift of the Palaeozoic core of the Cantabrian Mountains along a broken flexure zone, which generated a high relief during the Lower Tertiary. This is reflected in extensive piedmont alluvial fan-conglomerates parallel to the southern border fault.

The lithostratigraphic subdivisions of the Cambrian to Carboniferous sequences as proposed by Comte (1959) have been adopted with few alterations and are used as formations in the sense of the stratigraphic nomenclature proposed by the American Commission (A.A. P.G. Bull., v. 45, no. 5 (May 1961), p. 645—660).

The majority of Comte's type-sections are located in the Bernesga Valley and adjacent areas. These type-sections were reinvestigated and if necessary, supplemented. It was Comte who first pointed out the regional extensions of the Upper Devonian hiatus in his excellent stratigraphic studies (see table 1).

For the description of the Stephanian Matallana Basin a great deal of the data were obtained from an unpublished report by my colleague Van Amerom, who also determined the flora. Ciry (1939) studied the Mesozoic rocks in the area east of the Curueño River; extensive lists of fossils provide an adequate palaeontological control. Mabesoone (1959) published the results of a sedimentological study on the Tertiary and Quarternary rock units on the northern border of the Duero Basin.

In the present dissertation, four new formations are recognized in the predominantly coarse clastic deposits along the southern border of the Cantabrian Mountains. The type-sections are located near the village of Boñar in the lower Porma Valley.

Generally, the rock units in the Bernesga-Porma area have very outstanding features and are easily recognized and mapped over large distances. More detailed sedimentological and palaeontological features have not been mentioned in this thesis, if they were not considered necessary for the structural interpretation. To keep the description of the 24 formations as brief as possible, only major features are therefore covered. Since most stratigraphic sections were measured in subvertical middle limbs of large thrust folds, the thicknesses might locally be influenced by radial thinning or thickening and hidden repetitions due to strike faults.

LOWER PALAEOZOIC

The best exposure of the base of the clastic Cambro-Silurian sequence (Luna Group) is located in the valley of the Luna River (see structural index map) where an angular unconformity was mapped between the psammitic Herreria Formation and strongly folded, tilted and eroded slates and quartzites of Precambrian age (de Sitter, 1961; Pastor Gómez, 1963). This contact does not crop out in the present Bernesga-Porma area. The paucity of fossils makes time-stratigraphic correlations difficult, but the striking lithologic uniformity of the cratonic sediments over large regions makes comparison of the formations relatively easy (see app. III and IV, fig. 4).

An extensive study of the Cambrian rocks in Spain was made by Lotze and Sdzuy (1961) who were able to correlate the Cambro-Ordovician of NW Asturias through León to the Demanda Mountains east of Burgos (see location map and fig. 5). The distribution of Cambrian strata in NW Spain shows a geosynclinal development (thickness: 4—6 km) south of the present area and a non-sedimentary source area NE of the present area.

Table 1

Comte's subdivision (1959):	Thickness in m	Age	Formations
Conglomérates Argiles } de Castille		Miocène	Candanedo Vegaquemada
		— (lacune?) —	
Marnes de Boñar		Crétacé	Boñar
Graviers et Sables kaoliniques	± 200		Voznuevo
		— lacune —	
Schistes houillers et Grès de Tineo		Stephanien	Rucayo
Schistes houillers de Sabero	> 150		Sabero
		— lacune —	
Grès et Schistes de Sama		Westphalien	Sama?
Calcaire et Schistes de Lena	> 1000		Lena
Calcaire et Schistes de Villanueva		Namurien(?)	San Emiliano
Calcaire des Cañons	200—800		"Caliza de Montaña"
Griotte de Puente de Alba	25—40	Viséen	Alba
		— (lacune?) —	
"Couches de Vegamián"	± 15	Tournaisien(?)	Vegamián
		— lacune —	
Grès de l'Ermitage	0—1000	Strunien	Ermita
		— lacune —	
Schistes de Fueyo	± 100	Famennien	
Grès de Nocedo (Calcaires de Valdoré)	± 500		Nocedo
		— (lacune?) — Frasnien	
Calcaires de la Portilla	50—80	Givetien	Portilla
Grès et Schistes de Huergas	220—300	Eifelien	Huergas
Calcaires de Santa Lucia	100—250	Emsien	Santa Lucia
Calcschistes et Calcaires de La Vid	180—500	Siegenien Gedinnien	La Vid
Grès rouges de San Pedro	70—170	Silurien	San Pedro
Schistes du Formigoso	50—100		Formigoso
		— lacune —	
Quartzites de Barrios	160—480	Arenig	Barrios
Schistes et Grès d'Oville	120—240	Tremadoc & Potsdamien	Oville
		— (lacune?) —	
Griotte de Lancara	12—25	Acadien	Lancara
Dolomies de Lancara	45—80	Géorgien	
Grès de la Herreria	> 1400		Herreria
		— (lacune?) —	
		Précambrien(?)	

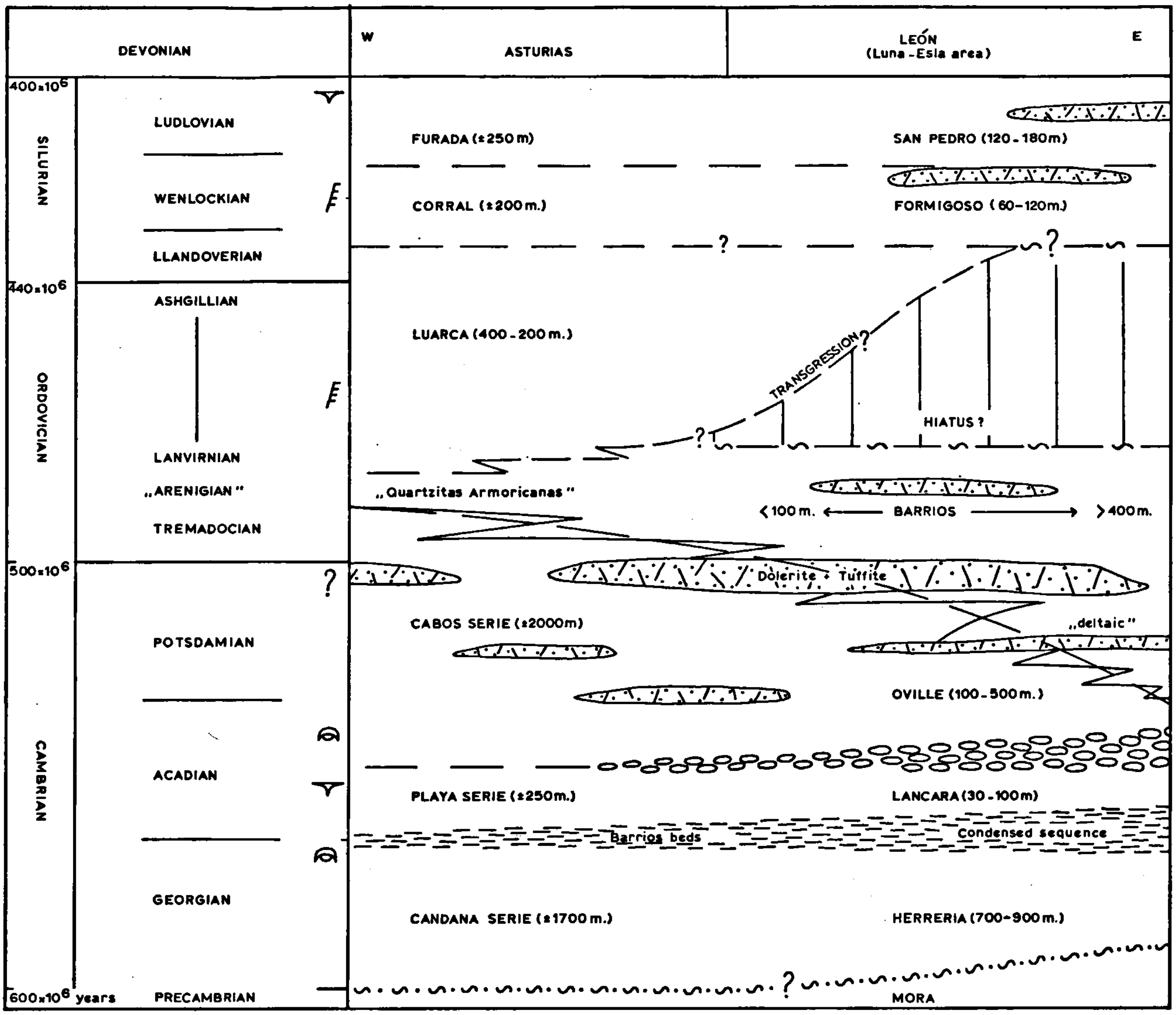

Fig. 4. Time-stratigraphic correlation of the Lower Palaeozoic in Asturias and León.

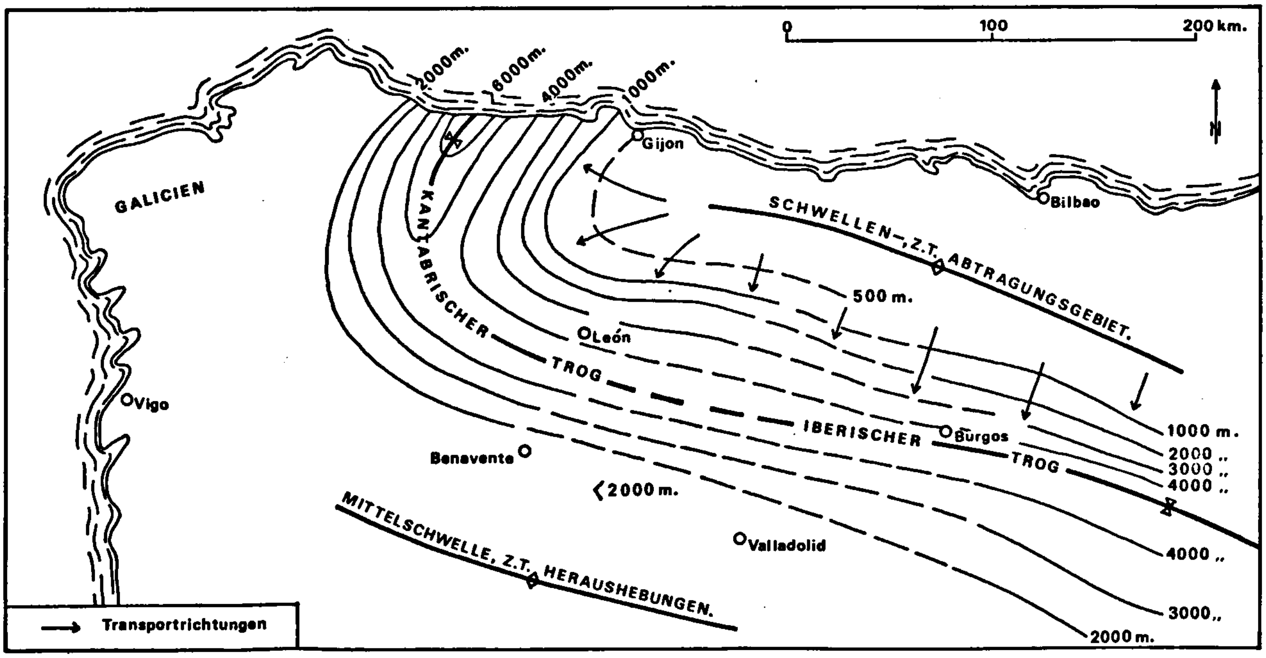

Fig. 5. Palaeogeography of the Cambrian in N.W. Spain; according to Lotze & Sdzuy (1961).

Herreria Formation (> 700 m)

The type locality of this formation composed of coarse gravels and sandstones, is defined by Comte (1959, p. 70) and situated in the present area along the left bank of the Porma River near the hacienda "La Herreria", 1 km N of Cerecedo. The section is limited at the base by the Porma Fault and probably includes repetitions due to upthrusts. The large outcrop of this tectonically disturbed formation along the Porma Valley led Comte to propose the unlikely thickness of 1400 m. In the undisturbed section of the Herreria Formation between Mora and Los Barrios de Luna however, the thickness is only 700 to 800 m. This thickness is accepted as a mean value in the present area, because the Herreria Formation in the Bodón Unit is of this same thickness and the limiting Bodón thrust fault is thought to have detached it at its bottom, where the greatest contrast in competency exists: i.e. between the metamorphosized Precambrian basement and the overlying Herreria sandstones.

The *lower part* (100—200 m) of this formation (app. III, 9) is composed of coarse-grained psammatic material. Several conglomerate and gravel beds, consisting of well-rounded quartzite pebbles (size: 3—10 cm) occur in lenses which can reach thicknesses of 3 m (fig. 6). Cross-bedding structures are frequently observed in these poorly cemented sandstones which shade from reddish-purple to yellow-white.

Fig. 6. Inclined stratification in conglomeratic beds at the base of the Herreria Formation, W. of Lugueros.

The *middle part* (ca. 400 m) of the Herreria Formation is best exposed along the new roads near the dam site in the Porma River. Medium to coarse-grained sandstones intercalate with green and red arenaceous shales, while cementation by quartz is much stronger.

The *upper part* (200 m) of the Herreria Formation was described by Oele (1964, p. 14). This section west of La Braña consists of quartz-sandstones with a few thin shale lenses but becomes more argillaceous and better cemented by hematite toward the top. Ripple marks, load casts and inclined stratification were often recorded. The early existence of life is indicated by worm tracks and burrows. Sandy dolomite lenses, partly built up of algae colonies (stromatolites), were found between Cerecedo and Valdepiélago and again north of Villanueva del Pontedo.

Oele (1964, p. 90) assumes a N-S direction of transport for the deltaic or lagoonal lower part of the Herreria Formation. The good sorting and continuous bedding features of the greater part of this uniform formation of considerable regional extent point to a shallow neritic environment.

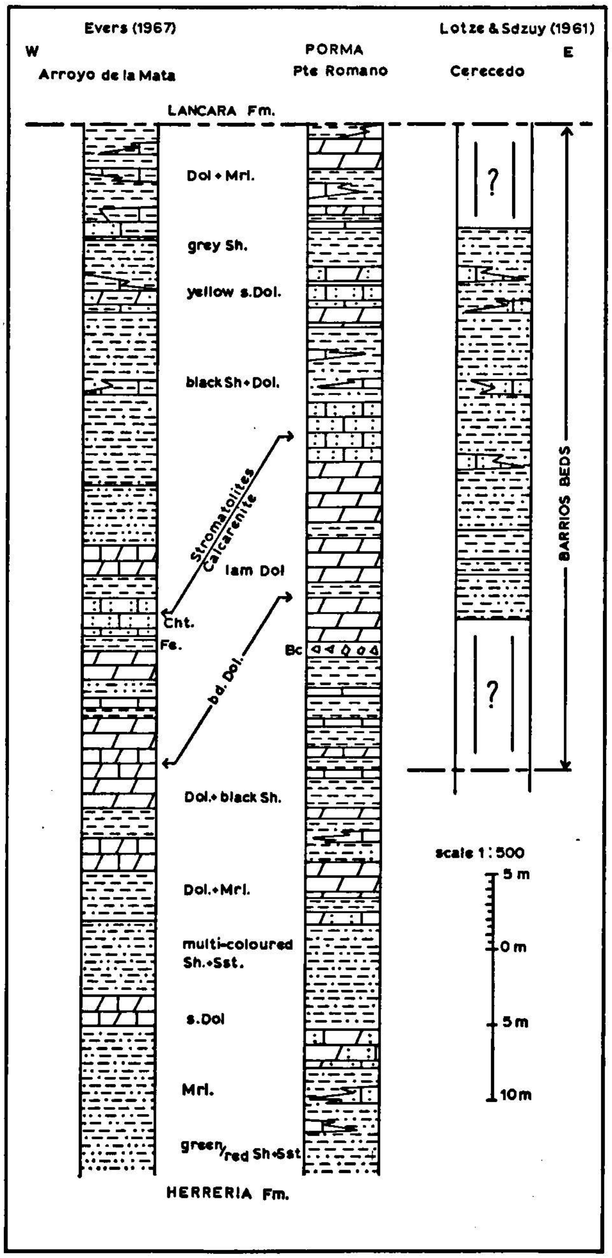

Fig. 7. Columnar sections of the gradual transition between the Herreria and Lancara Formations (i.e. "Barrios beds"); N of Boñar.

The gradual transition zone (10—74 m) between the Herreria and overlying Lancara Formation received little attention from Oele, but Lotze and Sdzuy (1961, p. 356) described these Barrios beds in some detail (fig. 7). It was in the black shales and marls near Los Barrios de Luna that Sdzuy dated one of the oldest trilobite faunas in the Iberic Peninsula as uppermost Georgian.

After the rapid accumulation of the Herreria sandstones, a sharp decrease in the supply of coarse terrigenous material occurred, while black pyritic shales and marls were deposited in shallow seas with restricted circulation.

Lancara Formation (32—95 m)

The type location of Comte (p. 71) is situated north of the village of Lancara de Luna. The best sections in the mapped area are located 2 km north of Boñar and along the road east of Pontedo de Torío.

The Lancara Formation can be divided into three members:

c. red nodular limestones ("Griotte"): 5—15 m
b. fine to coarse-grained limestones: 7—40 m
a. well-layered dolomites at the base: 20—40 m

The total thickness can vary from 32 m in the northern Forcada Unit to 95 m near Cerecedo. Differences in weathering and colour make these members easily discernable in the field; the fossiliferous "griottes" (c) can be used as a time-marker.

a. The yellow weathering dolomite member is composed of several carbonate rock types such as argillaceous dolomites, dolomitic limestones, oolites and breccias. The transitional black shales and calcareous mudstones are still intercalated in the thinly bedded lower part of the dolomite member. Well-sorted oolites, small angular limestone fragments and sub-rounded sand grains indicate a shallow neritic depositional environment. Van der Meer Mohr (1967) concluded intratidal conditions from the laminated algal-growth structures (stromatolites).

b. The limestone member is mainly built up of fine crystalline micrites (Folk, 1959), but fragmental limestone lenses and crossbedding structures in calcarenites were also recorded (Oele, 1964, p. 36). Glauconite occurs throughout the upper part of the Lancara Formation; concentrations of this mineral are encountered in the more condensed successions (10 m) in the northern Forcada Unit.

c. The red "griottes" on the other hand, are more abundant in the north; they consist of a typical alternation of ellipsoidal limestone nodules parallel to the bedding plane and red (hematitic) calcareous mudstones. The relative abundance of nonsoluble shell fragments, which gives an organo-clastic appearance to the "griottes", supports the assumption of Oele (1964, p. 49) that the nodular form is due to early diagenetic solution of the thin, evenly bedded limestone strata in a submarine environment. Trilobites and brachiopods of Acadian age were described by Lotze & Sdzuy (1961, p. 353 and 373).

Oville Formation (120—300 m)

The type locality by Comte (1959, p. 72) is situated just south of the village of Oville and is composed of alternating shale and sandstone beds. The transition from the red Lancara griotte to the overlying Oville Formation is gradual. The ferruginous shales change in colour from red to green and the lime-content decreases; but in the lower 10—20 m, many yellow decalcified sandstone nodules and calcareous sandstone layers still occur. The rate of sedimentation and the inflow of coarser detrital material increases gradually towards the top, resulting in progressively thicker sandstone beds.

Micas are present in variable amounts; some are converted to sericite, but the majority has been subjected to glauconitization. In the lower part of this formation many trilobites of the Paradoxides *mediterraneous* stage are found, indicating the upper part of the Acadian (Lotze & Sdzuy, 1961, table 7).

The bulk of the Oville Formation is however composed of unfossiliferous well-layered shale and sandstone beds. At approximately 100 m from the base, the calcite cementation has ceased and greenish glauconitic sandstones and quartzites predominate. A variety of bedding structures like ripple marks, crossbedding and load casts are exposed along the path from Montuerto to Nocedo. Concentrations of worm tracks were found on the bottom of the beds. These traces *(Scolithus linearis?)* are not widely accepted as diagnostic fossils, but according to Seilacher (1960) they indicate the Ordovician.

The great number of slump-structures are indicative of the unstable character of these shallow neritic deposits. The total thickness varies from 120 m in the northern sections to more than 300 m in the southern sections. The synsedimentary dolerites and tuffites in the Oville and Barrios Formations will be described at the end of this chapter.

Barrios Formation (250—350 m)

Comte (p. 74) described these orthoquartzites from a section near the village of Barrios de Luna. Several good sections through the Barrios Formation are encountered in the Bernesga Valley between Villamanin and La Vid.

The Barrios Formation is composed of thinly to thickly bedded orthoquartzites (> 75% quartz) and quartz-sandstones, intercalated by greenish micaceous shale lenses. Cementation by secondary quartz-growth is strong. The beds can wedge out rapidly, channel-cuttings, crossbedding and ripple marks were also recorded. The transition from the Oville Formation is gradual and therefore difficult to draw on the map; moreover, the boundary is generally obscured by large screes and dense vegetation. An exceptional conglomerate lens consisting of well-rounded, white pebbles (< 5 cm) was found in the upper part of the Barrios Formation NE of Boñar.

Most Spanish authors use the animal tracks *(Cruziana crucifera?)* to date the so-called "Quartzitas Armoricanas" as Arenig. The total thickness varies from > 350 m in the northern sections to < 250 m in the south. Oele (1964, p. 75 and 88) assumes a rapidly growing and interfingering delta-system as the specific depositional environment in which the Barrios Formation was formed.

Formigoso Formation (60—120 m)

Comte (p. 52—76) described these black shales from tectonically disturbed sections in the Formigoso Valley SE of Villamanin; less disturbed sections can be found around Villasimpliz.

The sharp, undulating boundary between the Barrios and Formigoso Formations as exposed north of Felmin, represents a nonconformity which is marked by concentrations of well-rounded, white quartzite pebbles. Comte (p. 125, 134 and 139) also concluded the existence of an important hiatus after the deposition of the Barrios Formation equalling the Luarca beds in Asturias (fig. 4). His main argument is the occurrence of the same Upper Llandoverian graptolites at the base of the Formigoso and Corral Formations.

The basal part of the Formigoso Formation consists of approximately 1 m of poorly sorted, coarse-grained sandstones varying in colour from yellow to green. They are overlain by 7 m of thin ferruginous sandstone lenses and mudstones. A striking black marl lens (ca. 1 m thick) is intercalated in the Felmin section; it has a detrital appearance due to the great amount of crinoïd stems and broken brachiopod and lamellibranch shells, indicating a highly energetic, shallow marine environment.

Towards the top, the grain size and phengite content decrease sharply and the sandy shales grade into carbonaceous black shales yielding many graptolites (fig. 8). The monograptoid assemblages determined by Kegel (1929, p. 40) and brachiopods mentioned by Comte (p. 52) indicate an Upper Llandoverian to Ludlovian age for the Formigoso Formation. Except for the small sandstone lenses, little stratification is found in the black micaceous shales, which were probably deposited in shallow water with little circulation and a lack of oxygen.

The transition to the overlying San Pedro Formation is gradual; sandstones start to predominate over shales and become increasingly coarser. In this ferruginous upper part of the Formigoso Formation many worm tracks are found. The variation in thickness of the Formigoso Formation from 60 to 120 m is partly due to tectonic squeezing of these incompetent beds.

San Pedro Formation (90—130 m)

The type location (Comte, p. 67 and 77) of these ferruginous sandstones is situated near the now inundated village of San Pedro de Luna. Good exposures in the present area are located around Villasimpliz and La Vid.

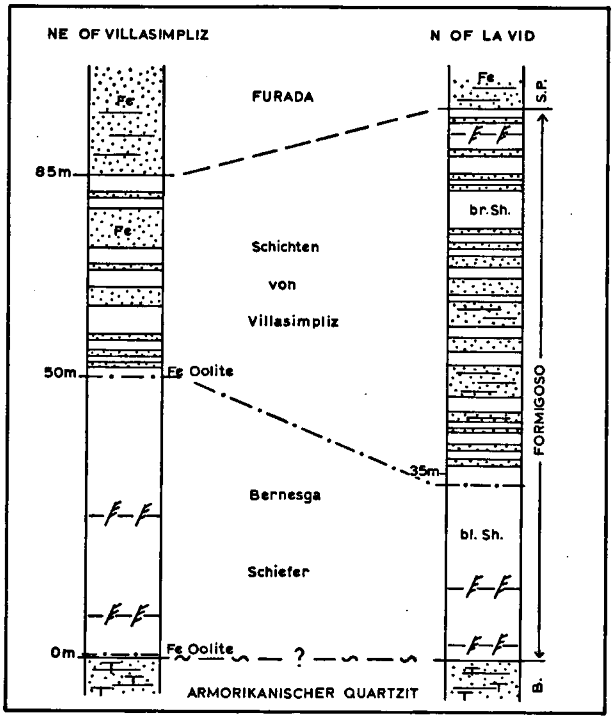

Fig. 8. Columnar sections of the Formigoso Formation illustrating the sharp basal contact and the gradual transition to overlying San Pedro Formation. Graptolite zones according to Kegel (1929).

A rapid increase in the rate of sedimentation occurred during the deposition of these coarse-grained, ferruginous sandstones. The lower part (ca. 40 m) of the San Pedro Formation is composed of well-bedded, brown quartz-sandstones intercalated by dark grey and green shale lenses. The upper part (ca. 80 m) consists of thick-bedded brown and reddish-purple ferruginous sandstones with locally a high iron-content. According to L. Cayeux (in Comte, p. 77), these ferruginous sandstones represent calcareous sandstones whose calcite cement altered into sideritic hematite concentrations.

The lime-content increases towards the top of the formation and calcareous sandstones and sandy marls intercalate with green arenaceous shales. The frequency of crossbedding, ripple marks and worm tracks in these moderately sorted sandstones might point to a shallow neritic or even littoral depositional environment. The striking white and green lapilli and volcanic glass are described at the end of this chapter.

Comte (p. 142 and 243) found several brachiopods that indicate the transition from the Silurian to the Devonian period; the upper part of the San Pedro Formation already belongs to the Gedinnian. The thickness varies from 90 m to 130 m.

DEVONIAN

Unlike the Lower Palaeozoic, the Devonian (Bernesga Group) is characterized by limestone formations although quantitatively, clastic rocks still prevail. Due

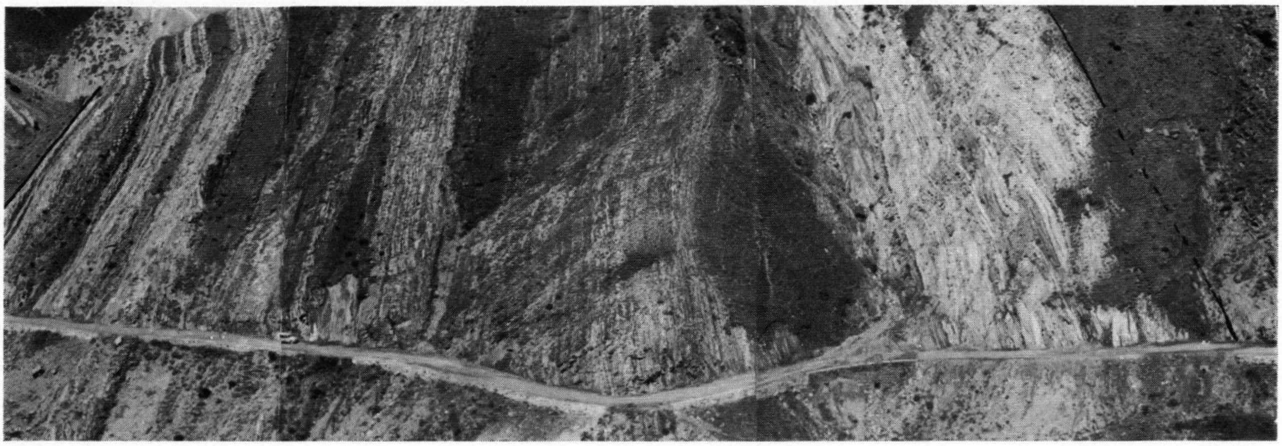

Fig. 9. The basal limestone member of the La Vid Formation in the type section along the road from La Vid to Villar.

to the rich faunal assemblages the relation between the easily recognized rock units and the biostratigraphy is good. The abundant spiriferid fauna appeared to be suitable for time-stratigraphic correlations with the West-European standard; see Comte (1959, p. 257).

Brouwer (1964 b) distinguished two facies types in the Devonian of the Cantabrian Mountains: the Asturo-Leonese facies in the Leonides in contrast to the Palentine facies in the eastern Asturides (see also Van Adrichem Boogaert, 1967).

A nearly complete Devonian succession was recorded in the lower Bernesga Valley, but in the NE part of the mapped area an Upper Devonian erosion period created an important hiatus, which is marked by the unconformity below the transgressive Ermita Formation overlying progressively older strata.

A grid of columnar sections was measured in or projected towards the four main river valleys which run roughly perpendicular to the E-W trending structures. These sections are compiled in appendices III and IV in the back pocket.

La Vid Formation (130—400 m)

The type-section by Comte (p. 169) was measured east of the village of La Vid in the Bernesga Valley. Because these dolomites and shales are so well exposed along the road to Villar del Puerto (fig. 9), several tectonic disturbances could be mapped, making Comte's total thickness of the type-section (ca. 500 m) questionable.

The La Vid Formation is divided into three members, which could be mapped throughout the area:

Top: red detrital limestones and shales (10—40 m)
greenish-brown shales and few marls (60—300 m)
Base: yellow to grey dolomitised limestones (40—190 m).

The transition from the San Pedro Formation is gradual and therefore difficult to map. The top of the underlying formation becomes more calcareous and the basal part of the La Vid Formation remains quite sandy. The lower member consists of sandy marls intercalated by dark shale lenses. The upper part of the member yielded many brachiopods, trilobites, tabulates, solitary corals, conodonts and crinoïds. The spiriferids indicate a Siegenian age (Comte, p. 318).

The second member consists of a thick succession of greenish-brown shales. Several detritical limestone lenses occur, but resistant or continuous markers are lacking. It is therefore impossible to determine to what extend tectonical disturbances have influenced the great thickness of these uniform shale beds in the type area.

The upper member consists of reddish-brown calcareous shales with a great number of crinoidal limestone lenses composed of more or less sorted fossil debris. The spiriferids collected in the top of the La Vid Formation indicate a Lower Emsian age (Comte, p. 304—307). Local variations in composition and thickness are shown in the columnar sections (app. III and IV) and in the palaeographic sketch map (fig. 15). Note the thin La Vid sections in the northern Bodón Unit (142 m) and south of Montuerto (130—150 m).

Santa Lucia Formation (155—230 m)

The type locality (Comte, p. 176) is found at the village of Santa Lucia in the lower Bernesga Valley, just south of the mapped area. The massive limestone banks of the Santa Lucia Formation are resistant to weathering and thus form well-exposed ridges flanked by the less resistant argillaceous beds of the La Vid and Huergas Formations. Because the general lithologic aspects of the Santa Lucia Formation are quite uniform, a differentiation into four prevalent limestone members could be made.

The transition from the La Vid Formation is gradual; several reddish detrital limestone lenses still intercalate the grey limestones at the base of the Santa Lucia Formation. The lower member consists of yellowish-grey, thinly bedded argillaceous limestones (30—40 m), which are irregularly dolomitized.

A 5 m thick transition zone of shale and marl beds preceeds the second limestone member, which is composed of thickly bedded biostromal limestone banks intercalated by black bituminous shale lenses. The biostromal banks are built up of well-cemented fossil debris and colonies of stromatoporoids; rugose corals are scarce. The irregular dolomitisation and silicification appears to be post-depositional, but authigenic chert nodules elongated parallel to the bedding plane also occur. The thickness varies considerably from 24 m near La Vid to 56 m N of Aviados and even 90 m N of Voznuevo.

The second and third limestone members are separated by a reddish-brown detrital limestone bed (ca. 8 m), consisting of concentrations of brachiopods, lamellibranchs, gastropods, rugose corals and stromatoporoids. These wave-built biostromal blankets indicate greater wave-action and shallower water depth. An Emsian age was determined by Comte (p. 318).

The third limestone member is composed of light grey biomicrites (ca. 40 m), overlain by dark-grey argillaceous biosparites (50—60 m). The polygonal desiccation cracks recorded west of Valporquero de Torío probably indicate sub-aerial periods (fig. 10).

Fig. 10. Desiccation cracks in the Santa Lucia Formation, 2 km W of Valporquero de Torío.

The fourth limestone member consists of a reddish detrital lower part (ca. 15 m) and a thin-layered arenaceous upper part (ca. 10 m), separated by a bryozoal-limestone layer (ca. 2 m). Concentrations of large specimens (4 to 7 cm) of *Spirifer cultrijugatus* indicate the top of the Emisian or Couvinian. The total thickness of the Santa Lucia Formation varies between 155 m and 230 m.

Huergas Formation (220—300 m)

The type location (Comte, p. 188) is situated near the village of Huergas in the lower Bernesga Valley and is composed of sandy shales. In the discussed area, no complete sections occur due to the Upper Devonian hiatus and faulting. Comte's sections in the Bernesga area and Rupke's data (1965, p. 21) in the Esla region are referred to.

In the Porma sections only the lower 100—150 m of the Huergas Formation are exposed. The basal member (ca. 50 m) consists of coarse-grained ferruginous sandstones and thickly bedded decalcified sandstones and sales, shading from grey to brown. The second sandstone member (ca. 40 m) contains greenish quartzite banks which are resistant to weathering. Crossbedding was frequently observed in these coarse clastics, but fossils are very rare.

The Huergas Formation in the northern flank of the Montuerto syncline (N of Aviados) is thickest. Here three members can be distinguished:

c. brown decalcified, argillaceous sandstones and carbonaceous and micaceous shale lenses containing silicious clay ironstone concretions. Maximum exposed thickness below thrust plane: ca. 60 m.

b. thickly bedded quartz-iron sandstones shading from yellow to reddish-brown; thickness: 30—50 m.

a. brown ferruginous sandstones and shales; thickness: 60—80 m.

In the section north of Ciñera, only the lower 67 m of the Huergas Formation are exposed; they also consist of coarse-grained, reddish-brown ferruginous sandstones and shales. Worm tracks, crossbedding and concentrations of purplish-red hematitic oolites were frequently observed.

In the Correcilla Unit west of Valporquero de Torío, the lower part of the Huergas Formation (0—60 m) is even more sandy and the iron content higher. These coarse-grained to microconglomeratic sandstones overly the Santa Lucia limestones with sharp paraconformable contact, but no traces of erosion are visible. Comte (p. 198) dated the basal part of the Huergas Formation as Eifelian.

The sections SW of Aviados seem to be complete, though strike-faults can be expected at the base of the formation. From base to top the following succession was recorded: a) shale and sandstone beds (50—60 m) intercalated by marl lenses (0—18 m) overlain by, b) micaceous shales with nodules (25—40 m), c) decalcified brown sandstone (3—6 m) and d) arenaceous dark shales with fossiliferous nodules and irregular limestone lenses (ca. 150 m). The gradual transition from the marly mudstones in the southern Bernesga (type-)section to the coarse-grained, ferruginous sandstones in the northern sections is shown in appendix III. The total thickness of the complete Huergas Formation varies from 220 to 300 m.

Portilla Formation (60—110 m)

The type location (Comte, p. 199 and 230) is found on the right bank of the Portilla brook, W of Matallana-Estación. In the field, the Portilla Formation can easily be differentiated into two resistant limestone members separated by a less resistant reddish, detrital limestone bed. The limits of this formation are difficult to set, because a gradual transition to calcareous shales or sandstones is developed on both sides.

The following composite section was measured from base to top, near Matallana-Estación, SW of Aviados and NE of San Adrian.

a. Thinly layered, coarse-grained arenaceous limestones; ranging in colour from yellow to grey, but weathering red to brown. Concentrations of brachiopods, solitary corals and crinoids give this member a biostromal aspect. Crossbedding occurs locally. Thickness: 5—15 m.

b. Well-layered, blue-grey limestones. The massive parts are rich in reefbuilding fossils. Thickness in the Torío-section: 15—30 m; NE of San Adrian and SW of Aviados: 50—60 m. In the latter sections, bioherms with flank deposits have developed. In contrast to the Santa Lucia Formation, compound rugose corals are abundant but stromatoporoids are rare.

c. Reddish detrital marls and wave-built biostromal limestones. The thickness is generally 10—25 m, but SW of Aviados, a 5 m thick coarse-grained calcareous sandstone lens and thicker biostromal lenses account for a total thickness of 40 m.

d. Massive, light-grey reef limestones and few shale lenses: 40—60 m. Locally, the biohermal dome-shaped structures interfinger with well-bedded biostromal limestones and calcareous shales (fig. 11). Partly silicified corals, bryozoans, brachiopods and a few stromatoporoids are found.

e. Yellow weathering, calcareous shales and sandstones with lenses of reef debris. Thickness: 10—25 m.

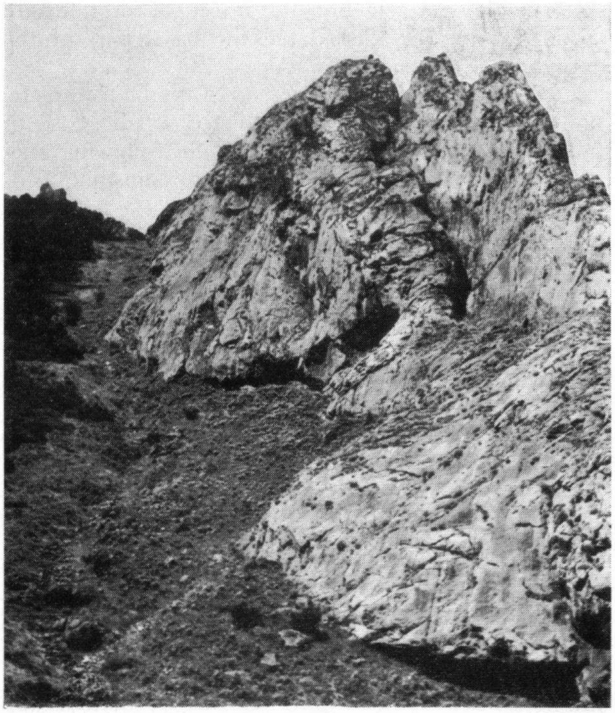

Fig. 11. The biohermal upper part of the Portilla Formation.

The total thickness of the Portilla Formation is generally 60—110 m, but SW of Aviados a conspicuously thick section of 170 m was measured. This is primarily due to a greater supply of debris and sand, but undetectable strike faults might also occur. The age of the Portilla Formation is determined as Upper Givetian and Lower Frasnian (Comte, p. 311 and 317).

Nocedo Formation (< 350 m)

The most complete Upper Devonian section was described by Comte (p. 190—194) near the village of Nocedo in the lower Bernesga Valley, where approximately 500 m of calcareous sandstones, quartzites and shales were measured. As a result of the basin configuration and the Upper Devonian hiatus, the Nocedo Formation is reduced to 350 m in the Torío-section near Matallana-Estación, to 250 m NE of La Valcueva and about 175 m near San Adrian. From the Bernesga and Esla basins towards the Pardomino Ridge, the sand grains tend to become coarser and increase at the cost of the shales and limestones.

From base to top, the following beds could be recognised in the basal part of the Matallana-Estación and Aviados sections (fig. 12):

a. Coarse-grained, calcareous sandstones and few quartzitic sandstones intercalated by thinly layered, blue reef limestones and dark green shales. Randomly distributed, iron-coated quartz pebbles are frequently found. Thickness: 28—34 m.

b. Erosional zone with scour-and-fill structures. Limestone breccia and conglomerate lenses of white and red ferruginous sandstone pebbles occur frequently. These pebbles are 2—5 cm in size and resemble the San Pedro sandstones. Towards the top, coarse-grained calcareous sandstones are interspersed with quartzites. Scour-and-fill and inclined stratification are observed frequently. Thickness: 20—25 m.

c. White and red decalcified sandstones and crossbedded, coarse-grained quartzitic sandstones intercalated by green arenaceous shales. Locally, a high iron-content and ripple marks were observed. Thickness: 40—46 m.

d. Arenaceous limestones grading into calcareous sandstones. These massive calcarenites are highly resistant to weathering. Crossbedding is frequently observed. Thickness: 10—18 m.

These basal beds can be combined into one calcareous lower member (100—130 m) in contrast to a predominantly quartzitic upper member. Comte (p. 213) called comparable beds in the Esla area: "Calcaire de Valdoré" (ca. 100 m). The abundant evidence of bottom-dwelling organisms and most sedimentological characteristics of the Nocedo Formation suggest a tidal flat area. Comte (table IV and p. 312—319) determined an Upper Frasnian to Lower Famennian fossil assemblage from the Nocedo Formation.

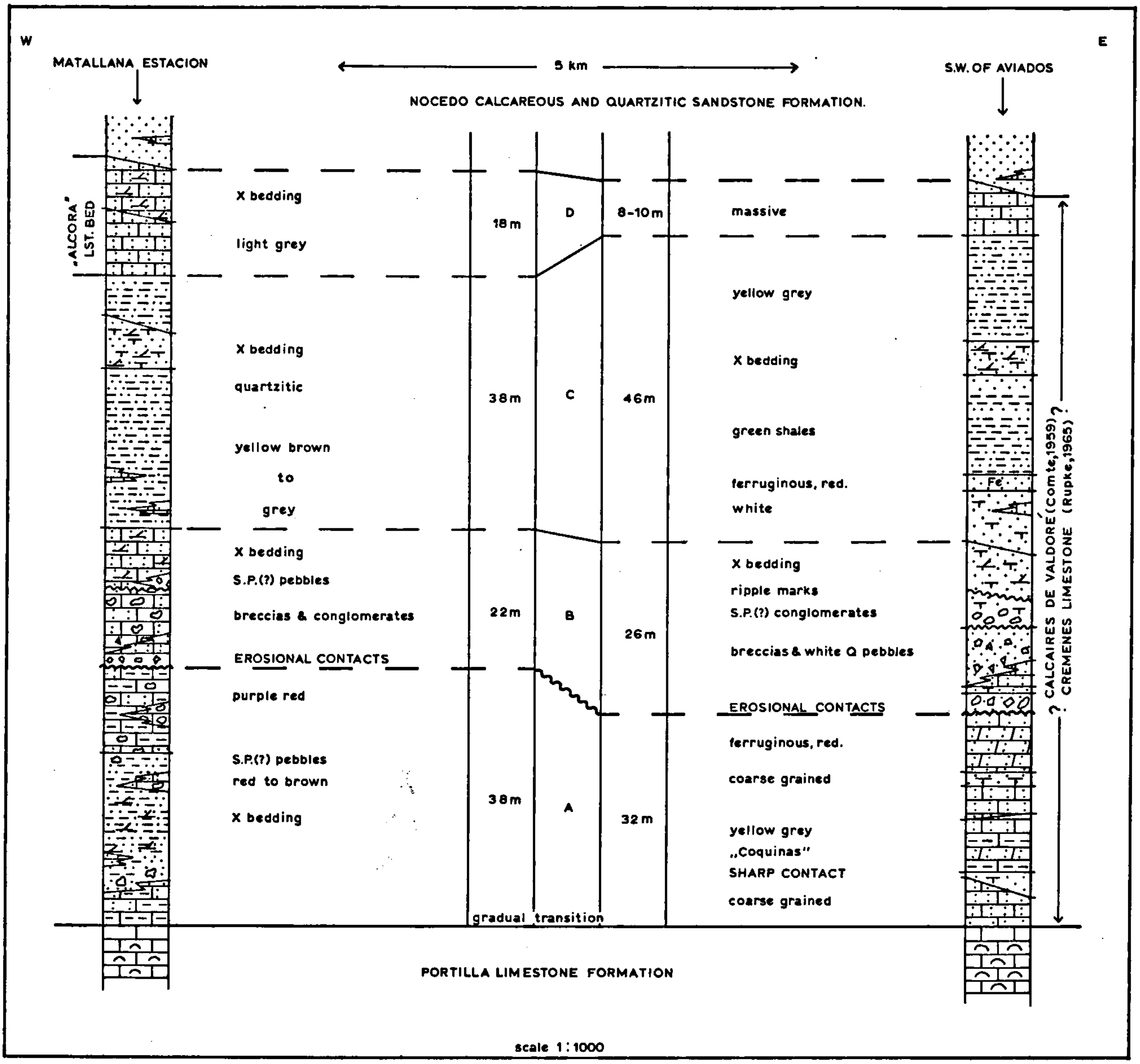

Fig. 12. Columnar sections of the base of the Nocedo Formation near Matallana Estacion and SW of Aviados. Note the erosional zones.

Ermita Formation (< 60 m)

The type location of the Ermita Formation (Comte, p. 193) is situated opposite the "Ermita de Buen Suceso" near the village of Nocedo in the lower Bernesga Valley. At this location the Ermita Formation consisting of calcareous sandstones, is very thick (ca. 140 m) and overlies the Fueyo shale member of the Nocedo Formation with sharp contact. North of the Sabero-Gordón line, the Ermita Formation is usually less than 10 m thick and unconformably overlies progressively older strata.

The base of the Ermita Formation is typified by microconglomerates, but the bulk is composed of calcareous sandstones and ferruginous quartz-sandstones locally topped by arenaceous limestones. In surface exposures these rocks are usually decalcified, creating fossil molds. Locally, the iron-content is high (30% near Valdorria; Comte, p. 203) resulting in purple-red colours. Major crossbedding structures occur throughout the section.

The high degree of sorting of the coarse-grained sandstones and crystalline limestones suggest a reworked littoral environment. Apparently, conditions were such that beach deposits were spread over a coastal plain in an almost continuous succession of parallel beaches. The transgression is marked by the sharp, paraconformable contact on top of progressively older rock units. Only on the map can the angularity of the nonconformity be deduced.

The Ermita Formation decreases towards the NE and even disappears between Canseco and Getino. This gap roughly corresponds with the Sancena culmination area of greatest Upper Devonian hiatus (Figs. 23 and 55). An abnormally thick (> 20 m) Ermita Formation is recorded in the Ferreras area (fig. 19). The basal part here yields microconglomeratic lenses of quartz pebbles (< 3 cm) and coarse-grained calcareous sandstones. A striking light-grey, coarse-crystalline limestone bank with a Strunian fauna could be mapped at most places in the top of the formation.

Since it is hard to differentiate the underlying Oville and Barrios Formations from the Ermita Formation, Comte (p. 201) mistakenly measured 250 m near La Braña and even 1000 m near Valdecastillo, although he found no fossils below the upper 25 m. Comte restricts the Ermita Formation to the Upper Famennian but recent conodont determinations by Higgins (1964) and Van Adrichem Boogaert (1967, p. 160) indicate a continuation into the Lower Tournaisian.

Concluding Remarks and Palaeogeography.

From the stratigraphic analyses of the Devonian in the Bernesga-Porma area, the following generalized conclusions can be drawn.

1. The alternating clastic and carbonate sequences have each been deposited in large areas of uniform lithologic aspects (fig. 13).
2. A good relation exists between the easily recognised rock units and the biostratigraphy.
3. Shallow, high-energy marine depositional environments prevailed, while several sub-aerial intervals occurred during the deposition of the Santa Lucia, Huergas, Nocedo and Ermita Formations.
4. The prevalence of biostromal over biohermal limestones suggests that subsidence was slow and about equalled depostition in a relatively stable shelf area.
5. The local concentrations or colonies of stromatoporoids, rugose and tabulate corals indicate special areas where conditions were favourable.
6. As shown in the palaeographic map (fig. 15), areas of less rapid subsidence are already obvious in the Lower Devonian (La Vid Formation); for instance, the León line separating the Asturo-Leonese and Palentine basins and the Pardomino line between the E-W striking Bernesga and Esla sub-basins; see also Brouwer (1964a), Rupke (1965, p. 39) and Van Adrichem Boogaert (1967, p. 169—173).

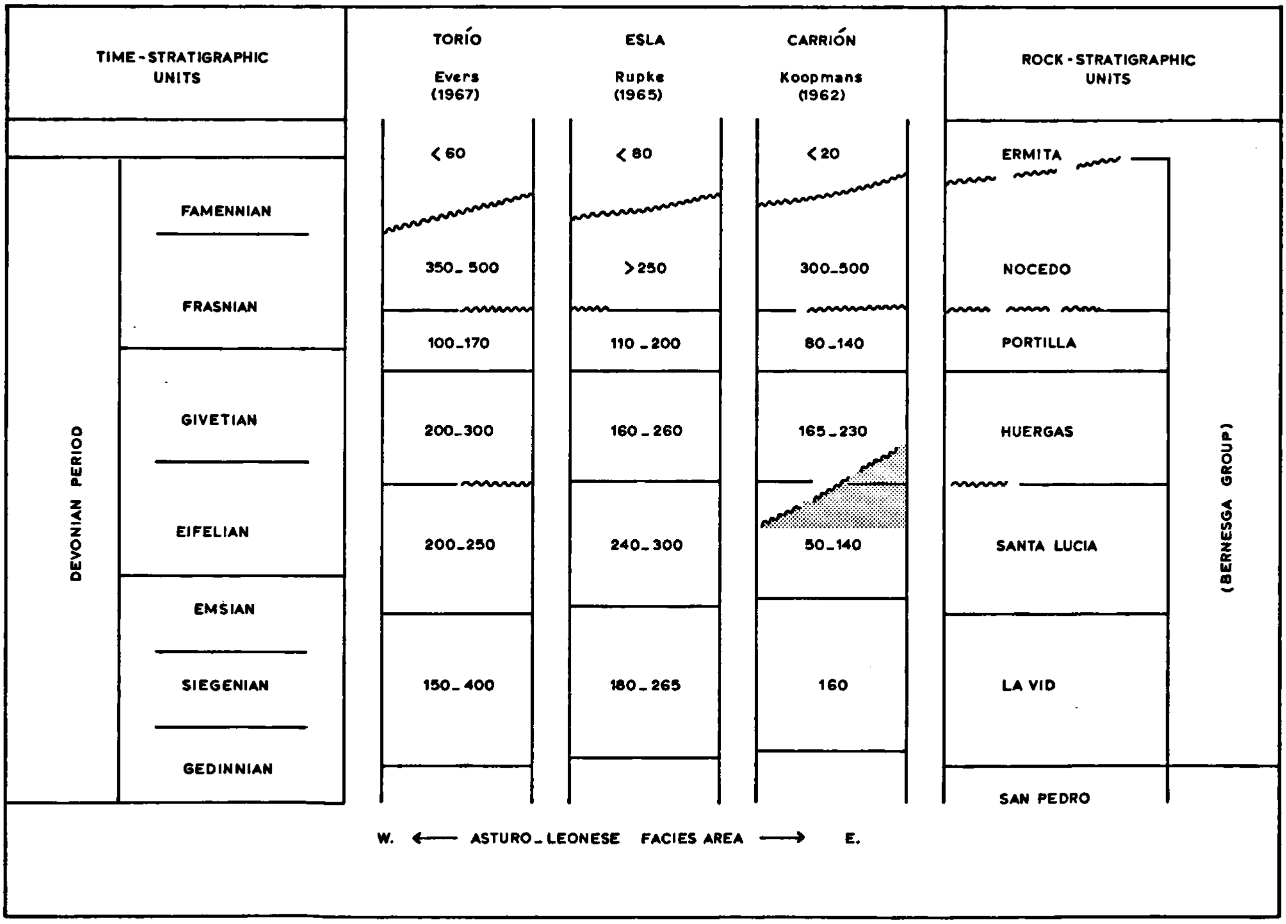

Fig. 13. Distribution of the Devonian rock units in the Leonides.

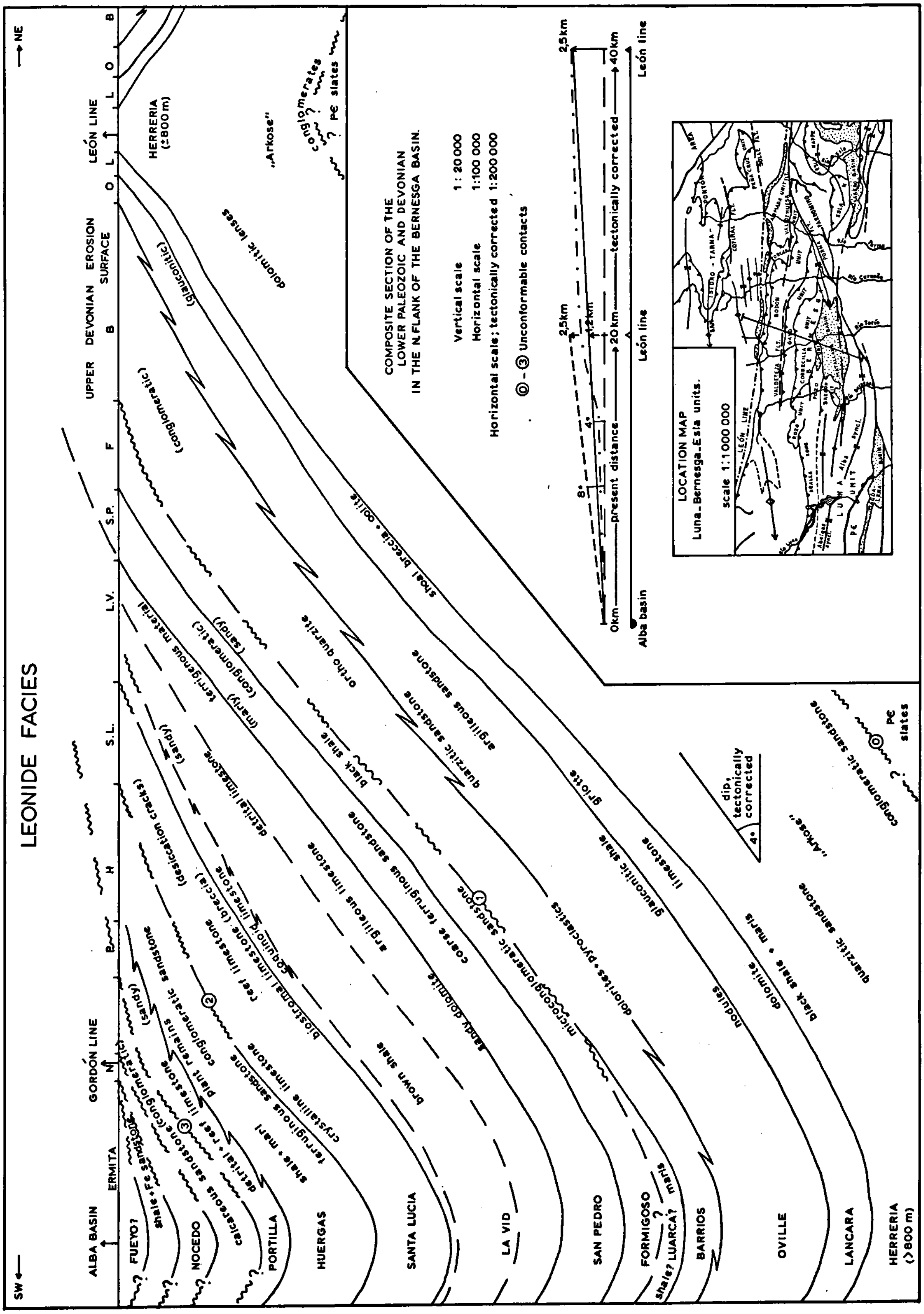

Fig. 14. Composite section of the Lower Palaeozoic and Devonian in the Bernesga-Porma area.

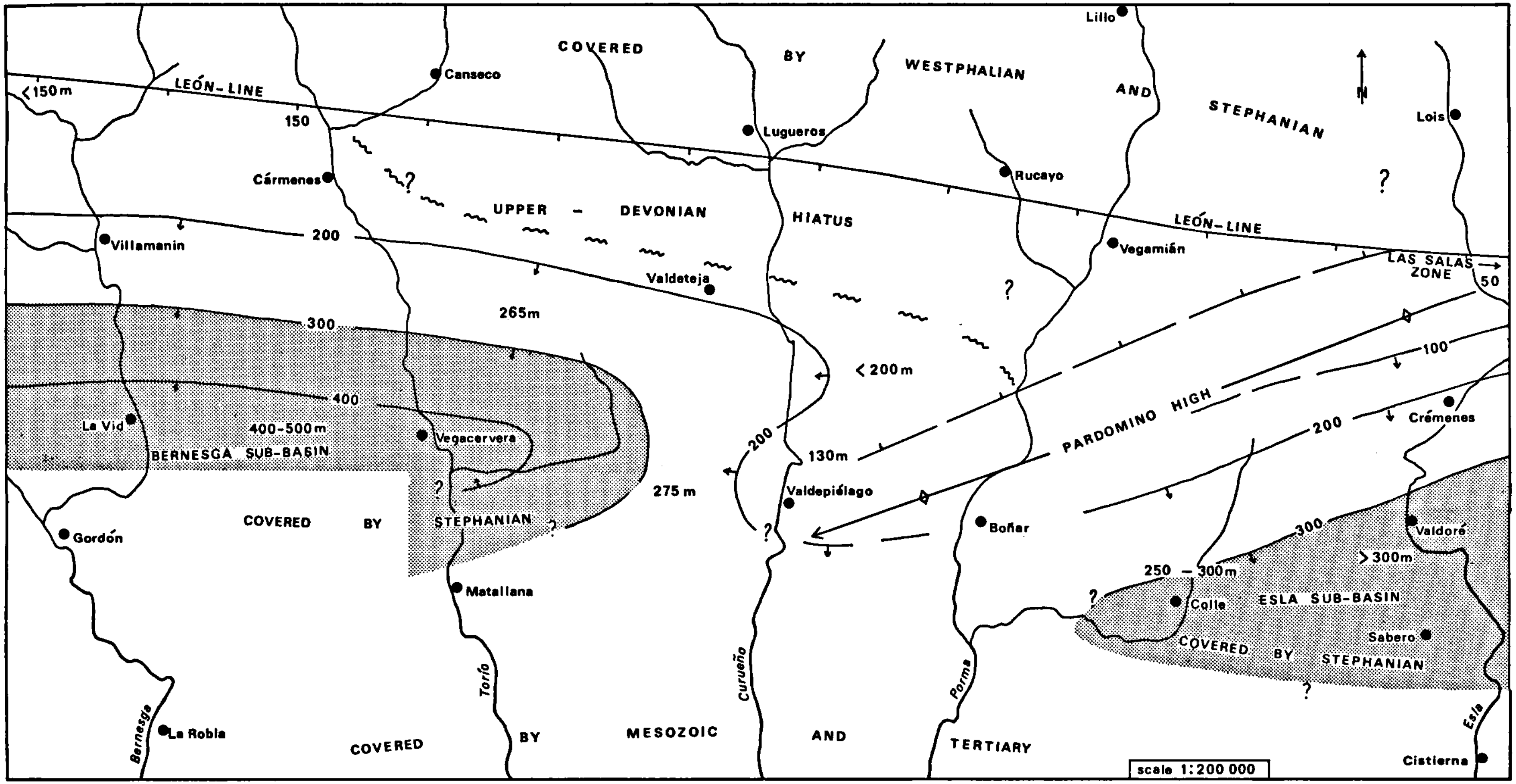

Fig. 15. Palaeogeographic map of the Bernesga-Porma area during the Lower Devonian, showing the distribution of the La Vid Formation.

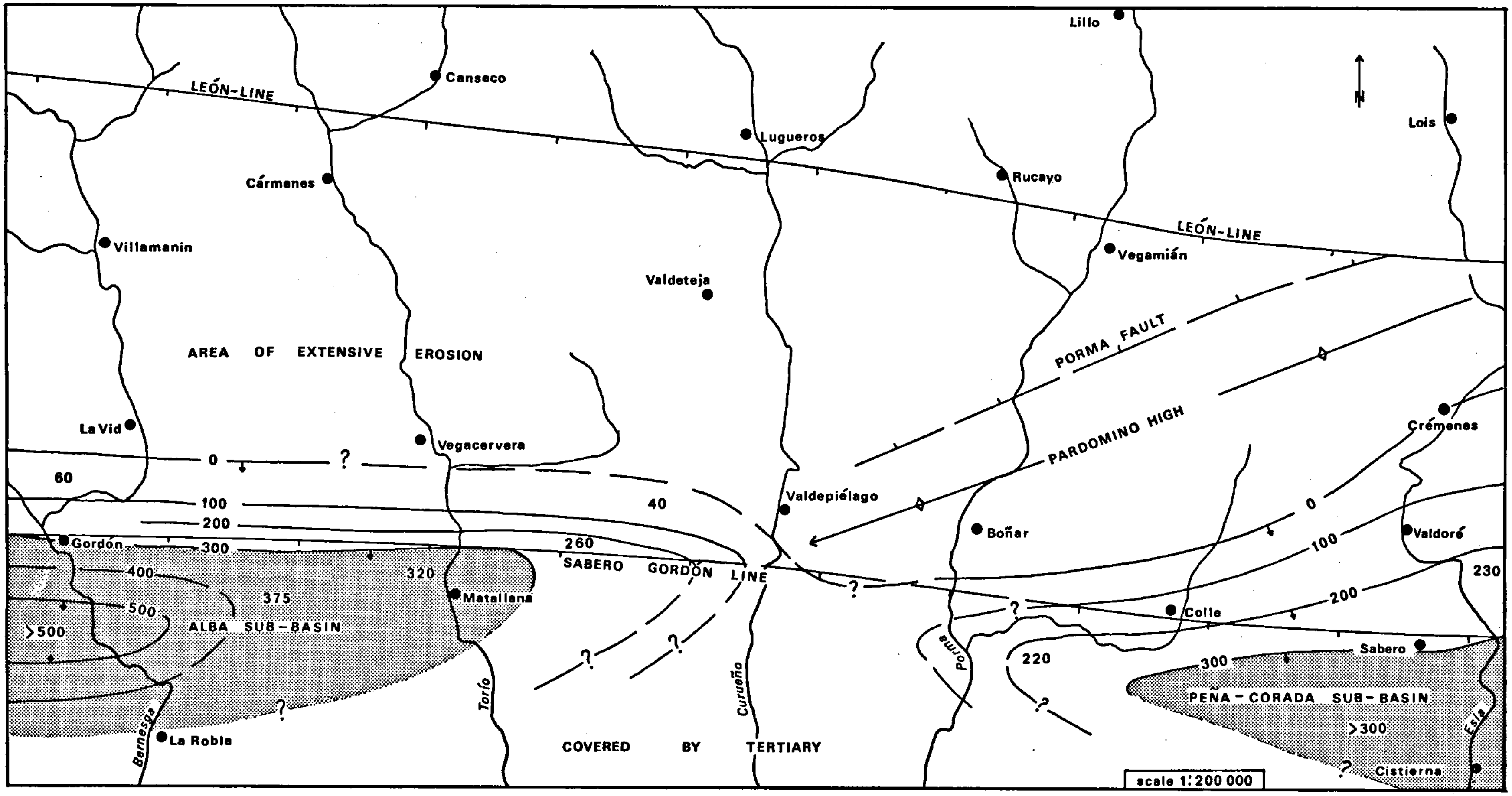

Fig. 16. Palaeogeographic map of the Bernesga-Porma area during the Upper Devonian, roughly showing the distribution of the regressive Nocedo Formation.

7. Considering the great lithologic uniformity in the Leonide facies area, it is probable that similar Middle Devonian condensed, partly terrigenous sequences (as described by Smits (1965) for the western Caldas area) and even important breaks (as recorded by Koopmans (1962, p. 173) in the eastern Carrión area, fig. 13) also occured near the León line in the present area. Desiccation cracks in the Santa Lucia Formation and the paraconformable base of the microconglomeratic and ferruginous Huergas Formation in the northernmost exposures already point in this direction.

8. Regressive offlap features in the Nocedo Formation mark the start of the Upper Devonian epeirogenic movements (Bretonic phase). The occurrence of ferruginous (San Pedro?) pebbles in the calcareous lower member suggests that an important amount of tilting and erosion had already taken place during the Frasnian north of the Sabero-Gordón line. This fundamental fault zone is further marked by continued subsidence and accumulation of the thickest Nocedo sections south of this line (app. IV).

9. The earlier concept of an extensive tilting of the northern part of a rigid Leonide block in a relatively short period during the Upper Famennian only and the subsequent erosion and removal of an equally thick column (ca. 1500 m) of Devonian rocks as exposed in the Bernesga sub-basin is not likely. The epeirogenic movements recorded during the entire Devonian reduced the total thickness of the Upper Devonian hiatus from > 2 km to < 1 km. According to this concept, the computed gradient of 60 m per km towards the northern edge of the asymmetric Bernesga Basin still indicates a respectable uplift.

10. As illustrated in figure 14, a large part of the hiatus was caused by nondeposition and sub-marine erosion due to little or no subsidence in the stable northern areas. A relatively small but rapid uplift during the Upper Famennian could therefore even result in the erosion of the Lower Palaeozoic. The Ermita Formation transgressed over a peneplane surface, because no important ravinements or basal conglomerates are recorded. The purely geographic name "Asturian Geanticline" as proposed by Van Adrichem Boogaert (1967), is therefore preferred over the time-restricted name "Bretonic Dome" as proposed by de Sitter (1965) for the area of greatest hiatus.

11. The stratigraphic and sedimentological properties of the "Grès de l'Ermitage" in the type-area south of the Sabero-Gordón line, do not suitably characterize the extensive distribution of the transgressive beach-sandstones overlying progressively older strata north of this line. Van Adrichem Boogaert (1967, p. 159) therefore proposed replacing the type-section to the first description by Comte (p. 166) at La Cantera, 2 km NE of Villanueva de la Tércia.

By correlating the litho-stratigraphic variations in composition, texture and thickness for the different Lower Palaeozoic and Devonian formations in a composite section (fig. 14) and in palaeographic maps (figs. 15 and 16), an interesting geological setting was derived. The important Upper Devonian hiatus and Hercynian deformations greatly reduce the interpretative value of these figures, but although the N-S gradient of the isopachs will be less steep when corrected tectonically, the regional trends are evident. It is not suprising that the isopical zones in the facies-pattern maps by Van Adrichem Boogaert (1967, p. 168—176) are limited by the same fundamental tectonic lines, since sedimentation is essentially controlled by the epeirogenic movements of the related basin and source areas.

CARBONIFEROUS

In the Carboniferous of the Cantabrian Mountains several formal rock units have been recognized. Koopmans (1962, p. 134—135) proposed a grouping of the formations marked by unconformities related to Hercynian tectonic phases (between branckets). Since tectonism was however not contemporaneous in the various regions of the Cantabrian Mountains, correlations with his Upper Carboniferous formations and groups in the Palentian area inevitably led to discrepancies and had to be abandoned.

Table 2

—— Saalic post-tectonic phase ——————

B. late-tectonic molasse facies (Cea Group)

—— Asturian paroxysmal phase ——————

A. syntectonic flysch facies (Yuso Group)

—— Sudetic early-tectonic phase ——————

carbonate and black shale facies (Ruesga Group)

—— Bretonic epeirogenic phase ——————

The present differentiation, already introduced in the beginning of this chapter, appeared most suitable for the Bernesga — Porma area. The terms flysch and molasse are here used as litho-facies, applied by most European geologists (Tercier, 1947) for syn — and post — orogenic sediments (tecto-facies), respectively. The flysch facies correspond greately with Pettijohn's (1957, p. 615) graywacke suite, which are often deposited in rapidly subsiding marginal basins or "clastic wedges" parallel to orogenic trends (Krumbein & Sloss, 1963, p. 535). The molasse facies are related to the subgraywacke association of Pettijohn (1957, p. 618).

Lower Carboniferous

The transgressive Ermita Formation marks the new invasion of the sea over peneplanized land-areas. The Lower Carboniferous formations have roughly the same wide distribution and are typified by black shale, griotte and lithographic limestone facies in condensed successions. Minor epeirogenic movements of the otherwise stable shelf area are indicated by sub-marine and sub-aerial erosion zones (Budinger *et al.*, 1964).

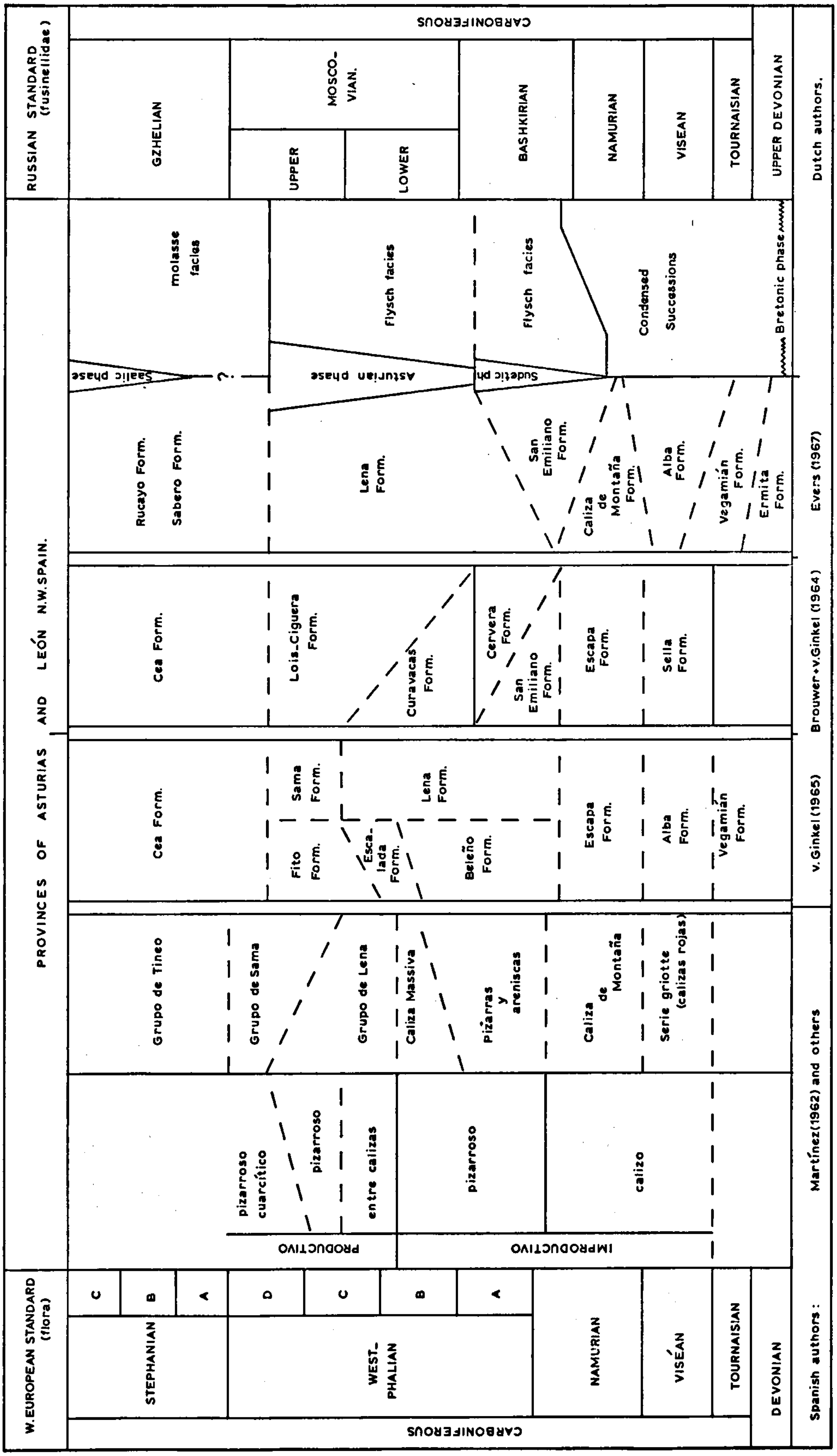

Fig. 17. Time-stratigraphic correlation of the Carboniferous rock units.

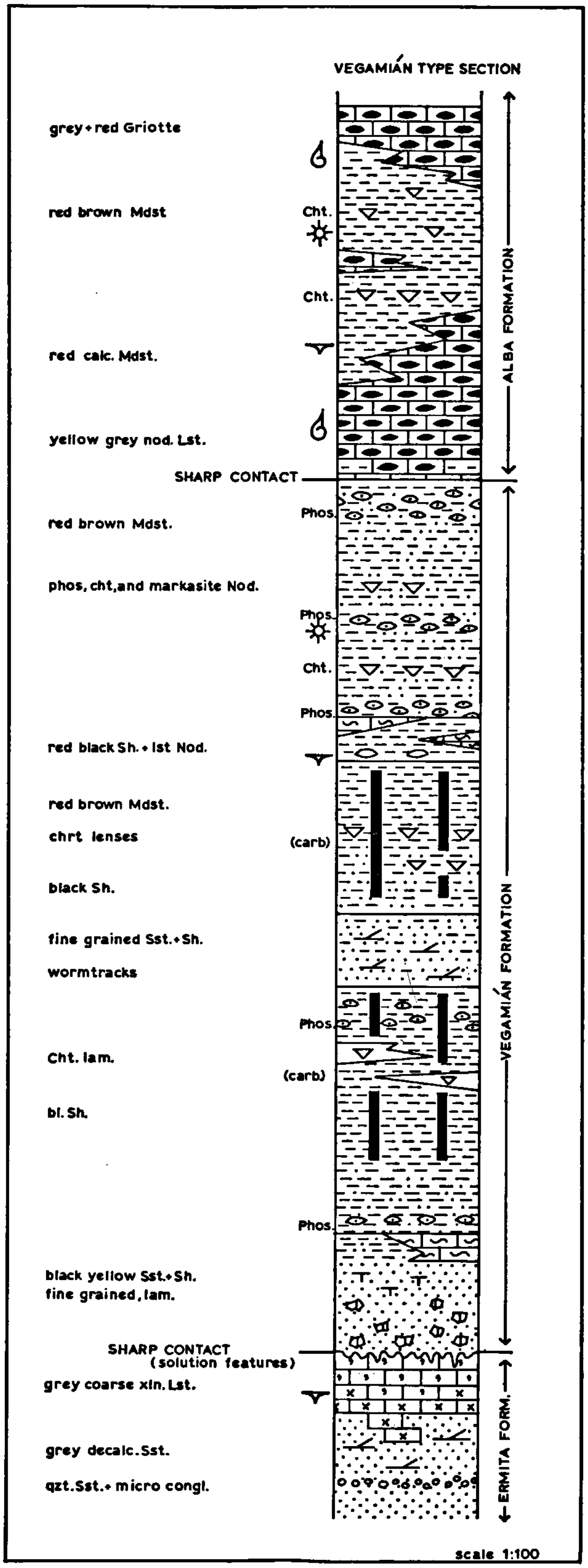

Fig. 18. New type section of the Vegamián Formation, S of Vegamián.

The use of old and well-known formal names is preferred to later suggestions by Brouwer and Van Ginkel (1964). For the readers' convenience and in an attempt to restrict the confusion about the regional lithostratigraphy of the Carboniferous in the Cantabrian Mountains, the subdivisions by different authors are listed in figure 17. The right-hand column agrees with the legend of the present geological map.

Vegamián Formation (< 15 m)

The "couches de Vegamián" were first described by Comte (p. 330) from an exposure south of the village of Vegamián in the Porma Valley. Because this section is now inundated by the artificial Porma Lake, another section was measured at a higher level along the new road (fig. 18).

The Vegamián Formation consists of thin layers of black shales and fine-grained argillaceous sandstones. At the base and top are concentrations of phosphatic nodules, while chert lenses can be found at various levels. In the Bodón and Forcada Units, an erosion surface with solution features and microconglomerates has often developed on the sharp unconformable contact with the underlying Ermita Formation; it marks a period of interrupted sedimentation.

Crossbedding and worm tracks are often found in the sandy parts of the formation, indicating an epi-neritic environment. The marcasite nodules and the scarcity of fossils in these laminated shales suggest temporary restricted conditions and a slow rate of sedimentation. Intraformational sub-marine disconformities are marked by local phosphatic zones, while the sub-aerial periods are shown by microconglomerates or sandstones and by the residual chert lenses.

Comte refers to Delépine, who in 1935 described Lower Carboniferous radiolarites in cherty marl and shale specimen from the type-section. Winkler Prins (in prep.) determined brachiopods in the muddy limestones of the Vegamián Formation in the present area. Higgins *et al.* (1964) and Van Adrichem Boogaert (1967) demonstrated an Upper Tournaisian to Lower Visean age for conodonts in the black shales of the Vegamián Formation in adjacent areas.

The thickness of this formation varies from zero to 15 m, but generally is less than 5 m. In tectonically disturbed areas however, these incompetent beds are often squeezed out or they can be piled up to more than 30 m. Small epeirogenic movements caused the local nondeposition or erosion of the black shales in Lower Visean times and resulted in a sharp upper boundary with the Alba Formation (fig. 19).

Higgins *et al.* (1964) measured several detailed sections in the Bernesga-Porma area which led to the following conclusions:

1. Sedimentation was continuous from Upper Famennian into the Tournaisian.
2. Uplifts during the Tournaisian locally eliminated a considerable portion of the Tournaisian succession.
3. Subsequent transgressive deposits consisting of thin basal sandstones and phosphate nodules are dated late Tournaisian and are followed by black shales.

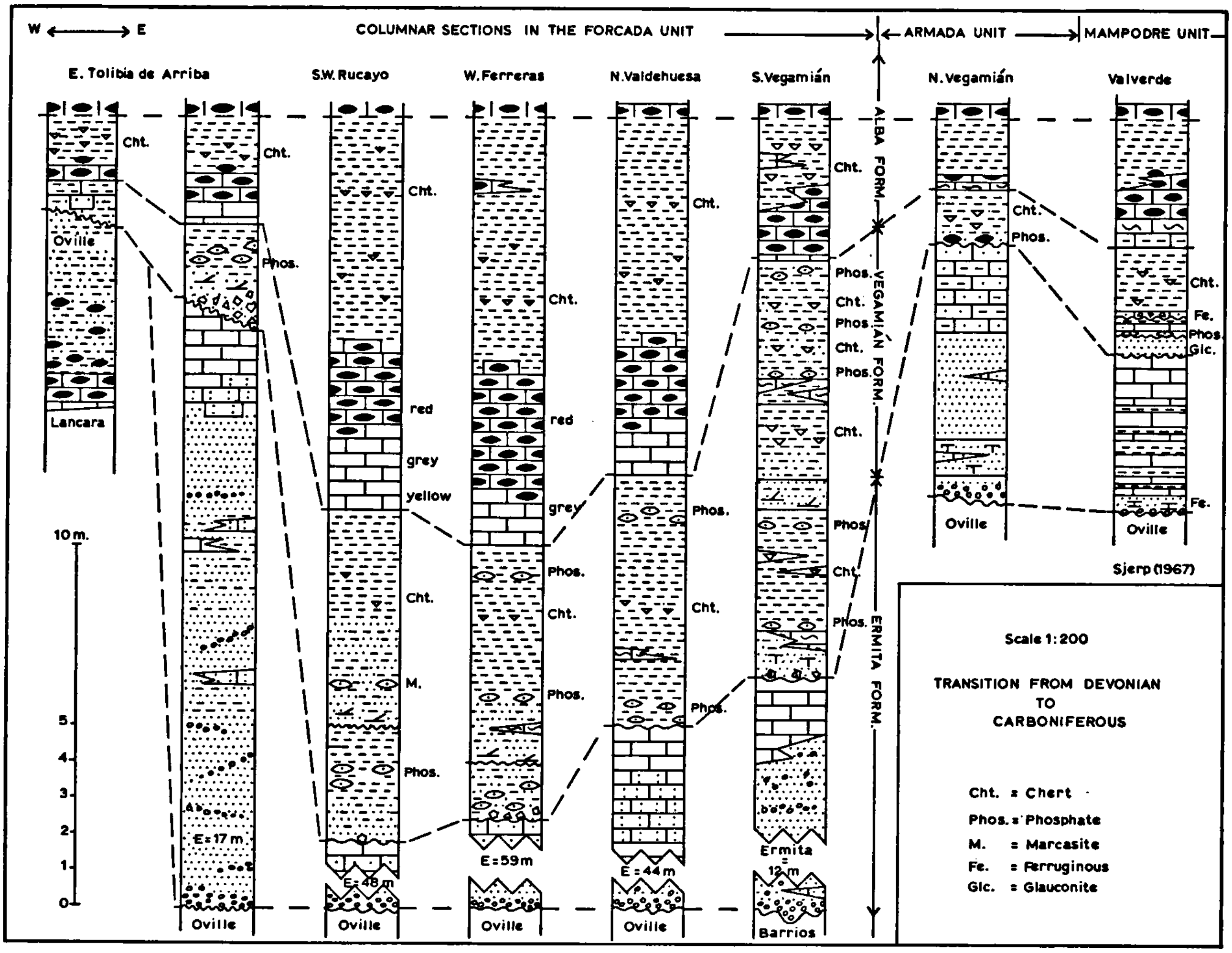

Fig. 19. Columnar sections of the Upper Devonian and Lower Carboniferous in the Ferreras area.

4. A second Carboniferous transgression is recorded in the southern part where conglomeratic sandstones with phosphatic nodules and casts of worm tracks occur above the black shales. In the northern Genicera section this transgression is not marked as a non-sequence.

5. The black shales pass gradually into the overlying grey to red nodular limestones, having a Lower Visean age based on evidence of conodonts (*anchoralis* zone) and goniatites (II β/γ zone). These nodular limestones pass into red shales and chert, overlain by the Alba Griottes (s.s.) of Upper Visean to Middle Namurian A age (E_2 zone).

6. Low-lying ridges seem to have been established briefly during the late Tournaisian in the northern part and during the early Lower Visean in the central (Sabero-Gordón line) area. A land mass was situated towards the south.

The last conclusion (6) is based on scanty information; specifically sample 1171 II might well be due to a stratigraphic "leak" which would strongly influence the conclusions.

Alba Formation (< 25 m)

The name Alba Formation has been used as designated by Comte (p. 40 and 330) for red nodular limestones and shales exposed S of the village of Puente de Alba in the lower Bernesga Valley. Good exposures in the area discussed here occur NW of Gete and S of Canseco. The wide extension and their typical red colour make the Alba "griottes" useful markers in the Cantabrian Mountains. The three members recognized in the Alba Formation were called (from base to top) the Gete (a), Valdehuesa (b) and La Venta (c) members by Winkler Prins (in prep.).

a. Yellow-grey, fine-grained nodular limestones with a tendency to become reddish towards the top. Thickness: 0,5—6 m, but generally 2 m. The lower member is rich in determinable fossils of Lower Visean age. The goniatites belong to the upper *Pericyclus* zone (Kullmann, 1963, p. 317) and to the II β/γ zone (Wagner-Gentis in Higgins *et al.*, 1964, p. 219). The conodonts belong to the *anchoralis* zone according to Higgins (in Higgins *et al.*, 1964).

b. Dark red to brown and green, thinly layered siliceous shales. Thickness: 4—8 m. The contacts with adjacent strata are gradual. No macrofossils were found, but concentrations of siliceous test of radiolaria occur.

c. Well-bedded, fossiliferous "griottes". Thickness: 10—33 m, being thickest in the northern Forcada Unit and thinning towards the south. The grey limestone nodules at the base of this member are floating in a mass of red calcareous claystones. The rounded and sub-angular nodules are flattened and always lie parallel to the bedding.

There is a gradual transition from red shales with limestone nodules at the base, to nodular limestones with a few red or green shale lenses, and ultimately laminated calcilutites intercalated by dark calcareous shales at the top. This transition probably indicates an early diagenetic solution and transportation of lime during breaks in the sedimentation of these transgressive beds; this resulted in a relative enrichment of the shales. The depositional environment was probably shallow neritic under oxidizing conditions.

A very good exposure of the upper member of the Alba Formation is located at La Venta, in the upper Curueño Valley, 3 km S of Tolibia de Abajo. The following beds could be distinguished:

1. yellow-grey argillaceous limestones — 4 m
2. purple-red nodular limestones — 5 m
3. dark grey limestones — 1 m
4. red and greenish "griottes" — 5 m

The three lower beds yielded ammonites, brachiopods, corals and crinoid stems. Kullmann (1963, p. 11—12) determined nine different species of goniatites belonging to the Go α, β and γ zones of the Upper Visean. The goniatites in the grey upper bed (4) indicate the E_2 zone of Lower Namurian (A); this bed marks the base of the overlying Caliza de Montaña Formation.

Caliza de Montaña Formation (0—750 m)

The massive limestones of the Caliza de Montaña Formation have not yet been described adequately. Since the early studies by Paillette (1855) the thick, massive limestones directly overlying the red griottes have been called "Caliza de Montaña" by most Spanish authors and until recently this informal name is used without specification of its rock-stratigraphic status.

The French School (e.g. Barrois, 1882; Delépine, 1943; Comte, 1959) uses the name "Calcaire des Cañons" for similar rocks in which many steep canyons occur. Several informal names were used in the same purely associative way, for instance "Caliza Metalifera" for the considerable mineral concentrations (see the end of this chapter), or just "Basal Limestones". In a recent publication, Brouwer and Van Ginkel (1964, p. 309) introduced the name Escapa Formation.

In the Bernesga-Porma area two members were distinguished in the Caliza de Montaña Formation (fig. 20 and 24):

b.	upper biosparite member	0—500 m
a.	lower micrite member	0—250 m

a. The micrite member consists of fine-grained, bituminous lithographic limestones with a dark grey to black colour. No recognizable macrofossils have been found in the limestones or in the intercalating black

Fig. 21. Lithographic limestones of the micrite member, E of Campillo.

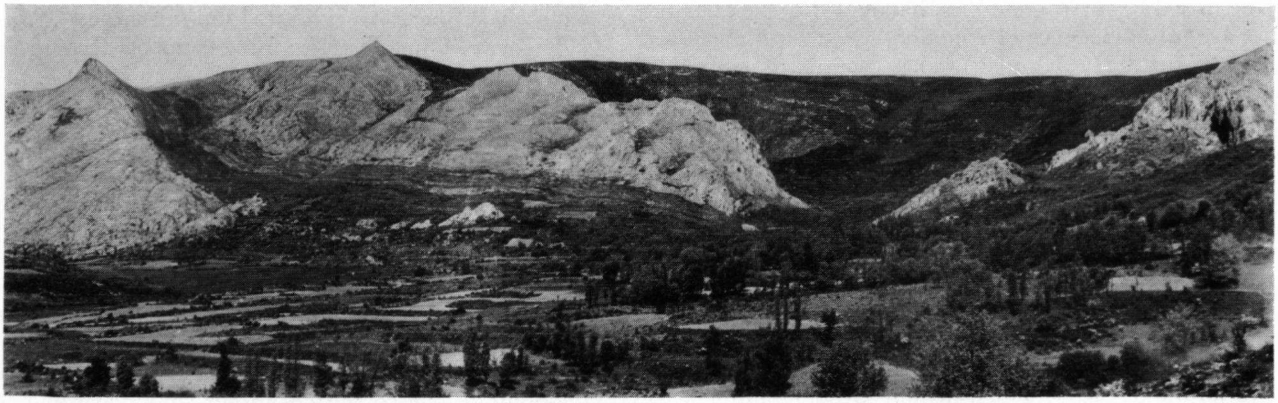

Fig. 20. The micrite and biosparite members of the Caliza de Montaña Formation, NW of Oville.

shale laminae. Especially in fresh exposures, the excellent stratification and platy character of this member are striking (fig. 21). The dimensions of these argillaceous limestone layers vary vertically from thinly laminated (< 1 cm) to well-layered (> 30 cm), but are almost constant laterally. These sub-crystalline limestones were probably deposited in a quiet and restricted environment, as suggested by the even bedding, the lack of fossils and the pyrite concentrations. Post-depositional recrystallization and dolomitization locally obscure the stratification, but are not related to the bedding plane.

The youngest goniatites determined at the base of this member indicate the Upper Visean to Lower Namurian; at the base of the fossiliferous upper member, a Lower Namurian B or Bashkirian fossil assemblage was described by Kullmann (1962), Wagner-Gentis (1963), Rácz (1964) and Van Ginkel (1965).

The thickness of the micrite member varies from about 250 m in the central area around Felmín and Valdeteja, to zero in the northern León line area (W of Canseco) and in the southern Alba syncline (see app. V and fig. 31).

At the top of the micrite member, a 20—60 m thick zone with sub-angular limestone fragments (< 20 cm) embedded in a matrix of unstratified red and black arenaceous and calcareous mudstones is encountered.

b. The biosparite member consists of a succession of light grey carbonate banks that normally overlie the limestone breccia zone in the top of the micrite member with paraconformable contact. They are composed of medium to coarse-grained, sorted biosparites, oösparites and related carbonates. Recrystallization and dolomitization obscure the thickly bedded, lenticular stratification of these biostromal carbonate banks, giving rise to their massive appearance (fig. 22). Though mound-like structures occur in the top of this member, they lack a framework of organically derived, sediment-binding material.

The transition to the interfingering San Emiliano Formation is normally gradational; organic debris and limestone fragments spread from the top of the massive biosparite member into the brown calcareous mudstones. The organic debris consists of bryozoans, solitary corals, gastropods, brachiopods and a large number of crinoid stems.

The fusulinids (Van Ginkel, 1965, p. 174) belong to the Millerella Zone, subzone Pseudostaffella antiqua; the calcareous algae (Rácz, 1964, p. 80) belong to Zone I. Both determinations indicate the Lower Bashkirian; comparison with the West-European standard reveals a Namurian B age (app. V and Van Ginkel, 1965, p. 205).

The biosparite member is barely developed in the northern Forcada Unit, where the top of the Caliza de Montaña Formation is marked by purplish-red manganeferous limestones overlain by a condensed (?) succession of red to yellow calcareous mudstones. These manganese concentrations are probably due to solution

Fig. 22. Mound-like structures in the dolomitised top of the biosparite member, W. of Cármenes. Photo taken from the Pico Fontún looking north; the highest peak is the Braña Caballo (2181 m), the road leads to the "La Profunda" mine.

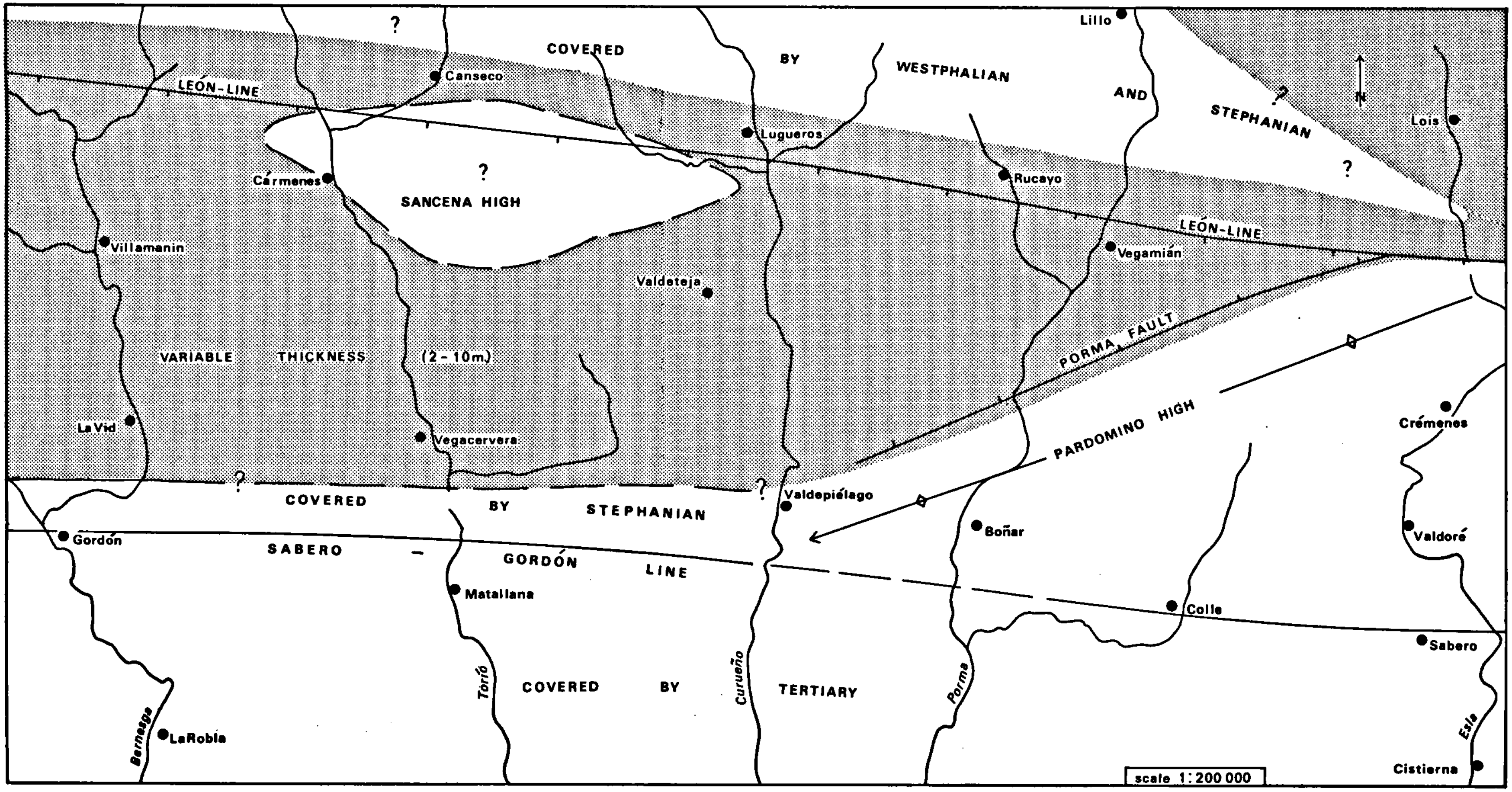

Fig. 23. Palaeogeographic map of the Bernesga-Porma area during the Lower Carboniferous; roughly illustrating the distribution of the Vegamián Formation (Tournaisian).

of the carbonates in a corrosion zone (Pettijohn, 1957, p. 216).

A shallow neritic depositional environment is suggested by the light-dependent corals and blue-green algea, the breccia and chert lenses, as well as the convolute-and crossbedding structures in the calcarenitic beds of the biosparite member (Illing, 1964).

Roughly the same subdivision of the Caliza de Montaña Formation in the Carmenes area was used by:

1. Delépine (1943, p. 10): black limestones (ca. 200 m) — light grey limestones (ca. 500 m).
2. Wagner (1963, p. 62): well-bedded, dark grey fetid limestones (100—400 m) — light grey, massive limestones (100—1000 m).
3. Winkler Prins (in prep.): Vegacervera member — Valdeteja member.

Concluding Remarks and Palaeogeography.

The Lower Carboniferous is marked by several regional and local transgressions and regressions in shallow seas resulting in small breaks in the quiet sedimentation. A nearly complete succession can, however, be compiled from various locations throughout the Cantabrian Mountains (Van Adrichem Boogaert, 1967). Considering the small total thickness (< 40 m) and the long life-time of the Lower Carboniferous Vegamián and Alba Formations = $(50 \pm 10) \times 10^6$ years, it is obvious that the black shales and griottes represent a condensed sequence.

The diachronous Ermita, Vegamián and Alba Formations as well as the lower micrite member of the Caliza de Montaña Formation have approximately the same extensive regional distribution. Minor epeirogenic movements along the established tectonic lines resulted in small areas where short periods of nondeposition, sub-marine or sub-aerial solution and shallow erosion occurred. In the present area, the Vegamián Formation is absent east of the Pardomino ridge and along the Sabero-Gordón line. In the local Sancena area, the Ermita, Vegamián and Alba Formations are greatly reduced in size and locally even absent (fig. 23). Small uplifts could result in important gaps in these condensed Lower Carboniferous successions, which lack terrigenous material because the land source areas were peneplanized or too far away.

Most sedimentological properties suggest shallow marine depositional environments. The stagnant water circulation resulted in an impoverished fauna (mainly mud dwellers) in the fine-grained, black bituminous shales with pyrite, phosphate and chert nodules.

The lower micrite member also represents a quiet depositional environment, but the limestone breccias and the intraclastic-to-oolitic character of the upper biosparite member indicate higher energy environments.

The lateral transition from the Caliza de Montaña Formation to the flysch facies of the San Emiliano Formation and the variable thickness distribution of the micrite and biosparite members reflect the early tectonic activities which resulted in local ridges and basins.

As shown in figure 31, the tectonic activity originated in the southern Alba area, where the Caliza de Montaña Formation is absent. The great inflow of clastic material resulted in a relatively low organic content and slower precipitation of carbonates. To-

Table 3

Properties	Lower micrite member	Upper biosparite member
1. colour:	dark grey to black	light grey
2. grain size:	fine to medium (calcilutite)	medium to coarse (calcarenite)
3. mode of deposition:	chemical	organogenic and chemical
4. fossils:	absent	rich
5. bedding:	uniformly thin	thick and lenticular
6. sedimentary structures:	none	crossbedding, convolution etc.
7. inclusions:	no quartz crystals	bipyramidal quartz crystals
8. mineralisation:	primary	secondary concentrations
9. distribution:	extensive	restricted
10. upper-contacts:	sharp paraconformable, often marked by limestone breccias	mixed gradation, lateral transition to flysch facies

wards the northern León line, conditions for carbonate precipitating organisms appear to be more favourable; consequently, thicker biostromal banks occur in the northern flanks of the marginal basins.

Sjerp (1967, p. 107, fig. 44) and Llopis Llado (1954, p. 57—66) drew isopach maps of the Caliza de Montaña Formation in the Central Asturian region, north of the present area. The interpretational value of such maps is not great due to the important syn- and post-sedimentary tectonism, for which no adequate corrections were made.

Some of the contrasting properties of the two limestone members recognized in the Caliza de Montaña Formation are summarized in table 3.

In spite of these differences, the two members are not easily enough mapped in the field to justify a raise in rank to formations.

A. Upper Carboniferous Flysch Facies

The Upper Carboniferous both in the Leonides and the Asturides is typified by syntectonic flysch facies in asymmetric marginal basins. The great variety of rock associations such as conglomerate, greywacke, sandstone, shale, limestone and coal beds are intricately interfingered in lenticular beds. The unstable depositional environment is also reflected by the slump structures and graded bedding of the greywackes in these tectonically controlled paralic basins (Dzulynski & Walton, 1965).

A review of the large number of Upper Carboniferous formations and their age determinations by fusulinids (Russian standard) was given by Van Ginkel (1965), who kindly examined several limestone samples from the present area for their fusulinid content (app. V).

The flysch deposits in the Bernesga-Porma area are subdivided into a San Emiliano Formation south of the León line and a Lena Formation north of this fundamental line. Both formations paraconformably overlie the Namurian Caliza de Montaña Formation, except for the southern Alba and Peña Corada basins where the Caliza de Montaña Formation is mainly absent and the flysch facies are encountered on top of the Visean Alba Griottes.

San Emiliano Formation (600—800 m)

The type-section is located in the upper Luna valley, north of the village of San Emiliano (Van Ginkel, 1965, p. 186). The most complete sections in the present area occur around Carmenes, where Rácz (1964) studied the limestone facies in association with the rockbuilding calcareous algae.

The flysch litho-facies of the San Emiliano Formation consist of an alternation of mudstones, fine to coarse-grained greywackes and limestones, intercalated by minor coal streaks. In the northern flank of the asymmetric Carmenes syncline a differentiation into at least three members could be made, but lateral changes restrict regional application of these members. The rapid changes in facies and thickness are primarily due to the syntectonic character of these youngest deposits involved in the E-W thrust-folding of the Leonides (app. V and fig. 24).

	N-flank	S-flank
c. mudstone and limestone member	0—250 m	± 50 m
b. mudstone and greywacke member	35— 60 m	±600 m
a. basal mudstone member	150—300 m	100—150 m
Total thickness:	185—610 m	750—800 m

a. The basal mudstone member consists of poorly stratified and convoluted mudstones with a yellowish to dark brown colour. Several coquinoid and limestone breccia beds pass like streaks of debris from the mound-like top of the Caliza de Montaña Formation into the slumped, calcareous shales and micaceous sandstones. Especially in the Gayo Unit around Nocedo de Curueño and again E of Fontún, several lenses of

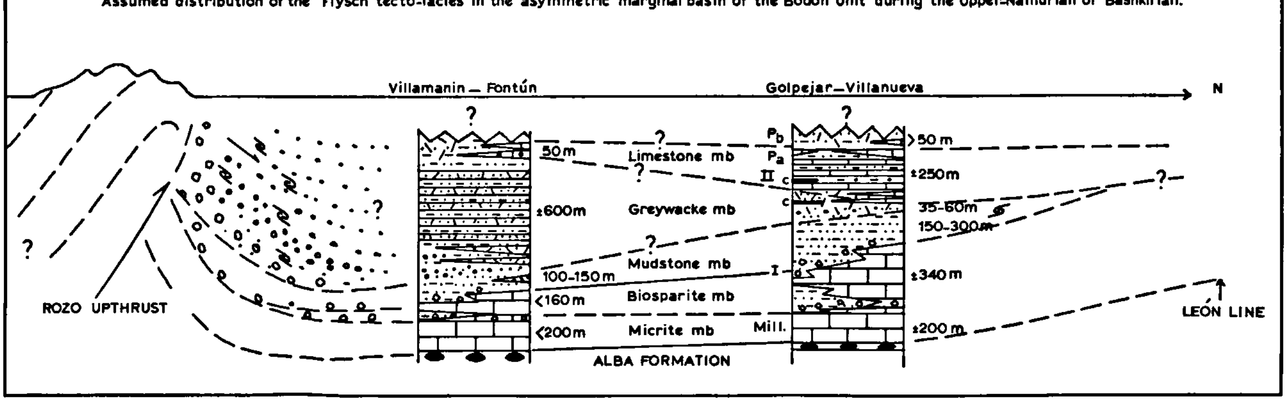

Fig. 24. Composite section of the Caliza de Montaña and San Emiliano Formations between Villamanin and Villanueva de la Tércia.

conglomeratic mudstones were found at the base of this formation. These "para-conglomerates" (Pettijohn, 1957, p. 261) show the abnormal association of well-rounded, jointed quartz boulders (5—30 cm) in a fine matrix of mud. They were probably deposited on the margin of a marine basin after a long and torrential transport. During or slightly after deposition, the mud with pebbles slid down the slope of the shelf, which had become unstable as a result of the early Sudetic) tectonism. Van Veen (1965, p. 67) mapped polimict conglomerates (< 120 m) of limestone and quartzite pebbles (Triollo member) at the base of the comparable Cervera Formation in NW Palentia; 40 km further east. They rest unconformably upon the Caliza de Montaña Formation and even Devonian formations, and are themselves unconformably overlain by the Curavacas Conglomerates. Another indication for early deformations in the reworking of older sediments which had already attained a rather consolidated state, are the sub-angular shale and calcarenite fragments in the basal mudstones.

b. The mudstone and greywacke member is built up of an alternation of dark brown carbonaceous sandy shales, well-bedded brownish greywackes (Boswell, 1960) and "cleaner" yellow-brown sandstones. The badly sorted, micro-conglomeratic to fine-grained greywacke lenses often show repeated grading in laminated lenticular beds. Shale fragments and red weathering ferruginous mudballs randomly distributed in the greywacke banks also indicate a pulsatory sedimentation, probably due to turbidites (Kuenen, 1950—1959; Bouma, 1964).

The railroad section west of Golpejar and the sections along the Bernesga River around Villamanin, present good exposures of the greywacke member, in which several quartz para-conglomerate streaks and unproductive coal seams (< 3 dm) of short lateral extensions have been recorded. Because the coal beds lack a seat-earth, they probably are allochthonous like the many plant remains in the greywacke beds.

c. The mudstone and limestone member consists of several light grey limestone beds intercalated between dark brown mudstones and few greywackes. More than seven limestone beds could be traced with few interruptions through the Carmenes syncline. The basal limestone beds are usually oolites, but higher in the section oolitic portions occur less frequently.

The thickness of these fine to coarse-grained biostromal beds varies rapidly from zero to 10 m and if they attain a reeflike appearance, the thickness increases to 30 m and more (around Barrio de la Tercia and Valverdin). Some greywacke lenses directly overlie limestone beds with a remarkably sharp contact. The quartz para-conglomerates and coal streaks persist in the limestone member of the San Emiliano Formation, suggesting an unstable paralic depositional environment.

The limestones are rich in fossils such as echinoderms, ostracods, gastropods, trilobites and bryozoans. Goniatites and corals were determined by Wagner-Gentis and De Groot, respectively (in Wagner, 1963). Brachiopods were first described by Barrois (1882, p. 577) near Villanueva de la Tércia, later by Delépine (1943, p. 24) near Carmenes and recently by Winkler Prins (in prep.). The fusulinids determined by Van Ginkel (1965, p. 187) belong to the Profusulinella Zone, subzone A. (fig. 25). Calcareous algae were collected by Rácz (1964, p. 18) from 10 different locations in the Carmenes syncline; they belong to his Zone II, which could be correlated with the biostratigraphic subdivision of Van Ginkel (locations: L 25 and L 353). These rich faunal assemblages indicate more or less accurately the Namurian; the most diagnostic fusulinids even indicate an Upper Bashkirian age for the bulk of the San Emiliano Formation.

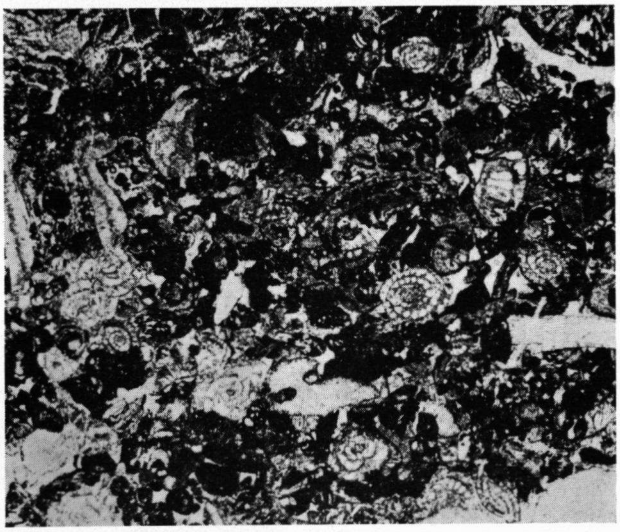

Fig. 25. Fusulinids and algae in the limestone member of the San Emiliano Formation, SW of Cármenes (25 ×).

Rácz (1964, p. 15) also mentioned the change in the facies from limestone beds in the northern flank to coarse greywackes with slumping structures in the southern flank of the Carmenes syncline. In figure 24, a similar lateral facies change is shown for the Bernesga section, NE of Villamanin. The limestone member wedges out towards the south and is replaced by about 600 m of arenaceous shales and thick coarse-grained greywacke banks, which probably belong to the second member. The reconstruction of the asymmetric flysch basin in front of a major upthrust suggests a syntectonic sedimentation pattern.

The flysch facies south of the Sabero-Gordón line

a. The Matallana-Estación section is situated in the eastern extension of the northern flank of the Alba syncline (app. V). The gradual transition upwards from red nodular limestones into dark grey micrites is absent and the Caliza de Montaña Formation is not developed. Thin streaks of calcilutites are followed by a convoluted zone of reddish-brown calcareous mudstones with angular and sub-rounded limestone fragments. Slump structures occur in the overlying micaceous shale and sandstone or greywacke layers.

These laminated banks are often coarse-grained and locally even micro-conglomeratic, such as the dark lydite-breccia lenses N of La Valcueva.

Many undeterminable plant impressions were found, but conditions never seem to have been favourable long enough to form rootbanks or minor coal seams; probably the plant remains were slumped together with the badly sorted clastic host-rock to their present allochthonous position.

Approximately 250 m from the base, thin and evenly bedded, micritic limestone beds with a wide lateral extension occur; they can be used as a marker in these otherwise uniform clastic deposits. Unfortunately, no diagnostic macrofossils were found.

In the overlying, rapidly outwedging alternation of greywackes, quartzitic sandstones and arenaceous shales, lydite microconglomerates and plant remains persist. Further west, erosion has left thick calcarenitic limestone beds overlain by another wacke succession. The maximum thickness measured in the Alba syncline is about 600 m (app. V).

b. The San Adrian section in the lower Porma area shows essentially the same rapidly changing facies, but the limestone to greywacke-and-mudstone ratio is higher than in the Matallana-Estación area. Further east towards the Peña Corada, this ratio approaches one. Here the detrital limestones resemble the upper calcarenite member of the Caliza de Montaña Formation, but no fossils were found. According to Rupke (1965, p. 29), the maximum exposed thickness of these "Culm" facies near Yugeros is approximately 800 m.

The flysch facies in the Forcada Unit

Directly overlying the typical manganiferous corrosion zone at the top of the Caliza de Montaña Formation, a (condensed?) sequence of red and yellowish-brown calcareous mudstones is developed, which includes nodular chert and pyrite concretions as well as angular limestone fragments.

These convoluted mudstones grade into micaceous shales and greywackes. The dark brown arenaceous shales contain much carboniferous material and many plant impressions, but seat-earth and coal seams are absent. The poorly sorted, medium to coarse-grained and even microconglomeratic greywacke lenses often show grading. The thickness of these crumpled deposits is difficult to measure; around Arintero however, it is not expected to exceed 400 m.

SE of Tolibia de Arriba, a dark grey, oolitic limestone lens was found at approximately 350 m from the base of the formation. The calcareous algae in this lens were determined by Rácz (internal report), who concluded that they might belong to his calcareous algae Zone III, indicating the Lower Moscovian. Germs (written communication) examined algae from a nearby outcrop and concluded the boundary of Zone II to III (app. V). These data lead to the conclusion that the youngest part of the San Emiliano Formation (s.l.) is reached and that the section in the Forcada Unit is much thinner (ca. 400 m) compared to the 800 m deposited in the Bodón Unit during the same period.

The development of the San Emiliano Formation in the Armada Unit and in other areas NE of the present map, is comparable to that of the Forcada Unit, because the basal part of the mudstone member resembles the Ricacabiello Formation (Sjerp, 1967, p. 82) while the oolitic limestone lenses correspond lithologically and palaeontologically with his Lazaró-limestone bed.

Lena Formation (1400—2700 m)

The Lena Formation is used as designated by Barrois (1882) to indicate marine to paralic greywacke associations in the adjacent Central Asturian Coal Basin near the village of Pola de Lena. Spanish authors use the name "Grupo de Lena" and, like Barrois and Delépine (1943), include the comparable deposits of the San Emiliano Formation in the same lithostratigraphic unit. This is a very natural correlation because the flysch litho-facies are quite similar and palaeontological data have shown a partial synchronism (fig. 17 and app. V).

Van Ginkel (1965, p. 187) adopted the name Lena Formation and described a section near the boundary between Asturias and León, south of the Vegarada Pass. This section was also studied by Rácz (1964, p. 19—23), who determined the calcareous algae collected from many locations. The fossiliferous limestone beds also yielded brachiopods, corals, gastropods, bryozoans and crinoid stems; the clastic beds contain ostracods and plant impressions.

Sjerp (1967) mapped the calcareous lower part of the Lena Formation as exposed in the NE part of the Piedrafita Basin. The more sandy southern part of this asymmetric basin in front of the Leonide thrust folds is included in the present map. The following three members grade vertically, and in part laterally, into each other.

top c) paralic to limnic greywacke member
b) paralic limestone and wacke member
base a) marine to paralic mudstone member

The lower member is roughly contemporaneous with the San Emiliano Formation, while the upper member might already belong to the Sama Formation (fig. 30 and Van Ginkel, 1965, p. 189).

Note the lithologic conformity between the subdivisions recognized in the Lena and San Emiliano Formations.

a. The mudstone member (40—600 m)

The intricately folded mudstones at the base of the Lena Formation consist of dark brown calcareous or micaceous shales and greywackes with plant remains. The intraformational limestone breccias and quartz conglomerates resemble those in the San Emiliano Formation and suggest similar sedimentary agencies. The few limestone lenses are usually oolitic (fig. 26), indicating a shallow marine depositional environment within the wave base.

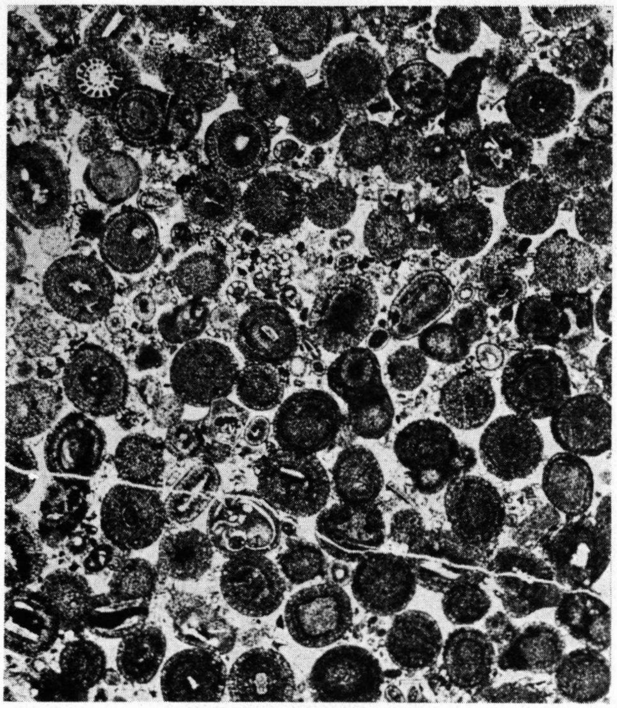

Fig. 26. Oolitic to pisolitic limestone at the base of the Lena Formation, E of Ferreras. Note the fusulinids and algal fragments (25 ×).

The calcareous algae in the top of this member belong to the top of Zone II or the base of Zone III; the fusulinids belong to the Profusulinella Zone, either the top of subzone A or the base of subzone B. Both data indicate the top of the Bashkirian or the base of the Moscovian (Vereyan, or Westphalian A). Sjerp (1967) determined the same age for his Lazaró limestone bed at the top of the mudstone member.

b. The limestone member (< 2000 m)

The great number of resistant limestone beds (fig. 27) provides the best mapped unit with considerable palaeontological control. These dark grey limestone beds are normally biosparites, but oosparite and micrites also occur. The thickness of the beds varies considerably from less than 1 m to over 100 m; the mean thickness is 3—10 m. In the northern part of the basin, the basal limestone beds normally have a thickly bedded to massive character and are therefore called "Caliza Massiva" by most Spanish authors. Most limestone beds have a large lateral (E-W) distribution, but wedge out towards the southern flank of the asymmetric Piedrafita Basin (fig. 30). The limestone beds become lenticular in form and oolitic in texture, while frequent intercalations with medium to coarse-grained greywackes occur. Such a distribution suggests a large supply of detritic material from the uplifted Leonides, so that thick carbonate beds could not be formed in the southern margins, while turbidity currents distributed the clastic sediments further into the basin.

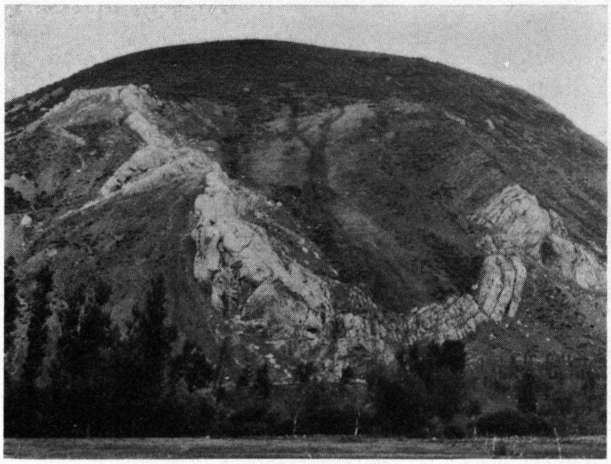

Fig. 27. Limestone bed in the Lena Formation, N. of Lugueros.

The limestone beds are randomly dolomitized. Pyrite occurs frequently in the fine slates. The laminated arenaceous shales are intercalated by medium to coarse-grained greywacke lenses with sharp basal contacts. The algae and corals indicate a shallow neritic depositional environment, but the thin coal veins point to sub-aerial periods in an unstable, paralic depositional environment.

c. The greywacke member (> 900 m)

This member consists of arenaceous shales, micaceous sandstones and greywacke beds, which are usually graded in laminae. The grain size varies greatly from fine to coarse and even microconglomeratic. Plant remains occur in variable concentrations in these reworked and slumped greywackes (fig. 28).

Several productive coal seams are located in this upper member; the number and thickness of the seams generally increases towards the top of the Lena Formation. In contrast to earlier coal lenses, these seams have a

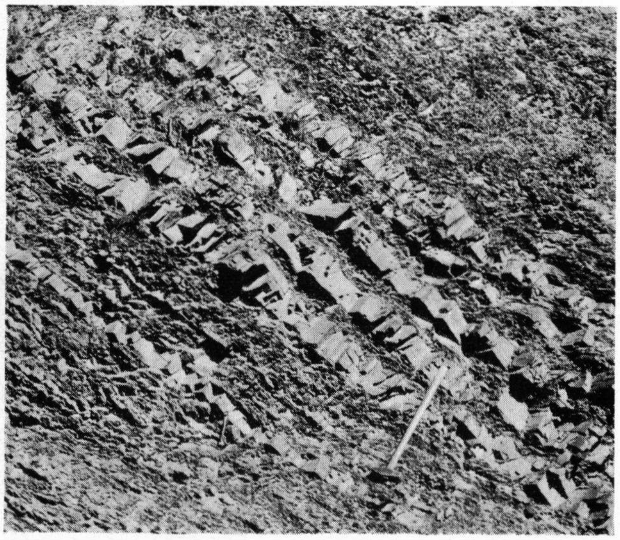

Fig. 28. Well-bedded greywacke and mudstone alternation with sharp basal contacts. Lower part of the Lena Formation near Campillo.

larger lateral extension and are based by seat-earth. The autochthonous character of the coal indicates longer intervals of continental depositional environments and an ultimate filling of the basin at the end of the orogenic phase. No detailed floral age determinations are available in the present area.

The few biostromal limestone beds are thin and lentiformal in shape; they also contain oolitic and detrital material. The youngest calcareous algae determined by Rácz (1964, p. 81—83) belong to the top of Zone III, or Zone IV. The fusulinids determined from locations along the León line between Canseco and Rucayo belong to the Fusulinella zone, subzone B and according to Van Ginkel (written comm.) indicate the base of the Upper Moscovian or the lower part of the Westphalian C (see location map and sections in app. V).

The flysch facies in the Ferreras area

Approximately 2 km south of Lodares and 5 km east of Campillo, a small exposure of Caliza de Montaña (50—100 m), based in the south by Alba griottes and topped by a manganeferous "corrosion" zone and nearly 20 m of calcareous mudstones (Ricacabiello Formation?), occurs in front of the Forcada Unit. This succession is overlain by more than 250 m of coarse-grained greywacke beds which wedge out rapidly. The two overlying darkly coloured argillaceous limestone lenses of Moscovian age were also mapped by Rupke (1965, p. 30), who regarded the greywackes as Herreria Formation.

In the Ferreras area west of the Porma River, the Caliza de Montaña Formation is not exposed due to the Forcada upthrust and a very thick and uniform accumulation of coarse-grained greywackes marks the basal part of the Lena Formation (fig. 28). Because no major tectonic complications were mapped north of the Valdehuesa fault zone, a thickness of over 1000 m is accepted. The supply of detrital material was apparently large, while slumps and turbidites gave rise to thick accumulations.

The base of the limestone member is typified by small oolitic limestone lenses (fig. 26) between calcareous and carbonaceous sandy shales and greywackes with drifted plant remains. In the fourth oolitic limestone bed from the base, Van Ginkel (written communication) determined *Profusulinella* ex gr. *parva* (Lee et Chen), and *Profusulinella ovata* (Rauser-Chermoussova), many *Parastaffella* species and a few primitive *Eofusulina* species. The abundant *Profusulinella* species resemble the assemblages of location L 25 in the top of the San Emiliano Formation (SW of Carmenes) indicating the top of the Profusulinella Zone, subzone A or even the lower part of subzone B (Vereyan). On top of this location east of Ferreras, several oolitic and pisolitic limestone lenses were mapped before the first resistant, thickly bedded biosparite lenses (0—40 m) appear around Quintanilla. The fusulinids here indicate the transition from the Profusulinella to Fusulinella Zone or the Lower Moscovian.

South of the path from Quintanilla to Vegamián, several quartz paraconglomerate lenses were found, but in contrast to the Curavacas area, no unconformity could be mapped.

Most limestone lenses north of Quintanilla are still oolitic in texture and laterally change into arenaceous shales and greywackes intercalated by coal streaks (fig. 29). The northernmost limestone beds before the Rucayo Basin belong to the Fusulinella Zone, subzone B or the Upper Moscovian. This implicates that the Quintanilla section, which decreases in age towards the north, represents a complete Bashkirian to Moscovian succession of the Lena Formation in the southern flank of Piedrafita Basin (sections 25 and 26 in app. V).

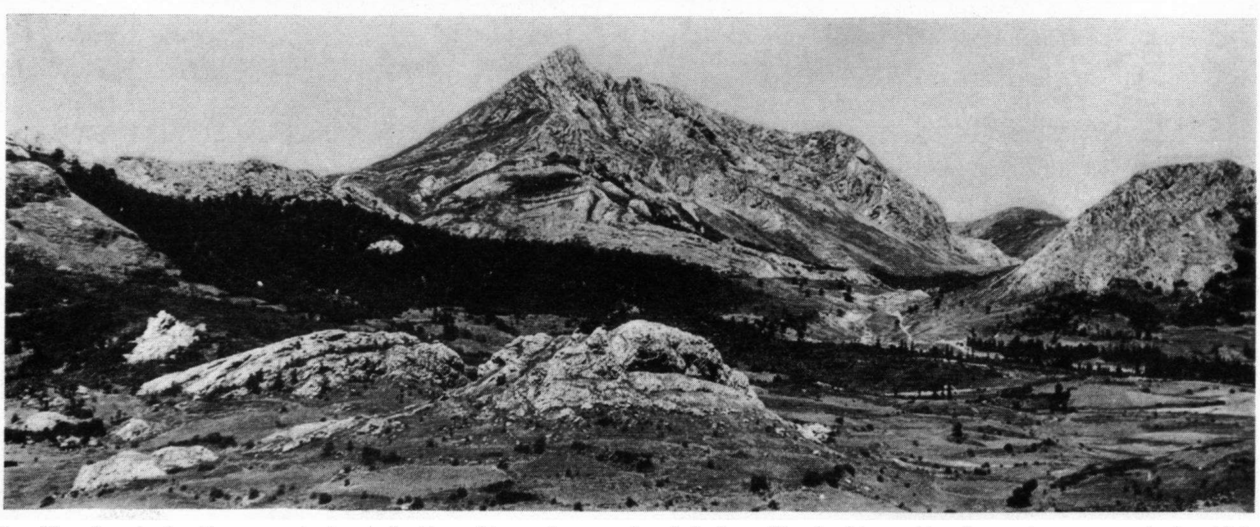

Fig. 29. Lenticular limestone beds of the Lena Formation north of Quintanilla de Vegamián, becoming progressively thicker and uniformal in the Susarón Mountain at the rear. At left-hand side, massive conglomerates of the Rucayo Formation; at the right, the Caliza de Montaña Formation of the Armada Unit.

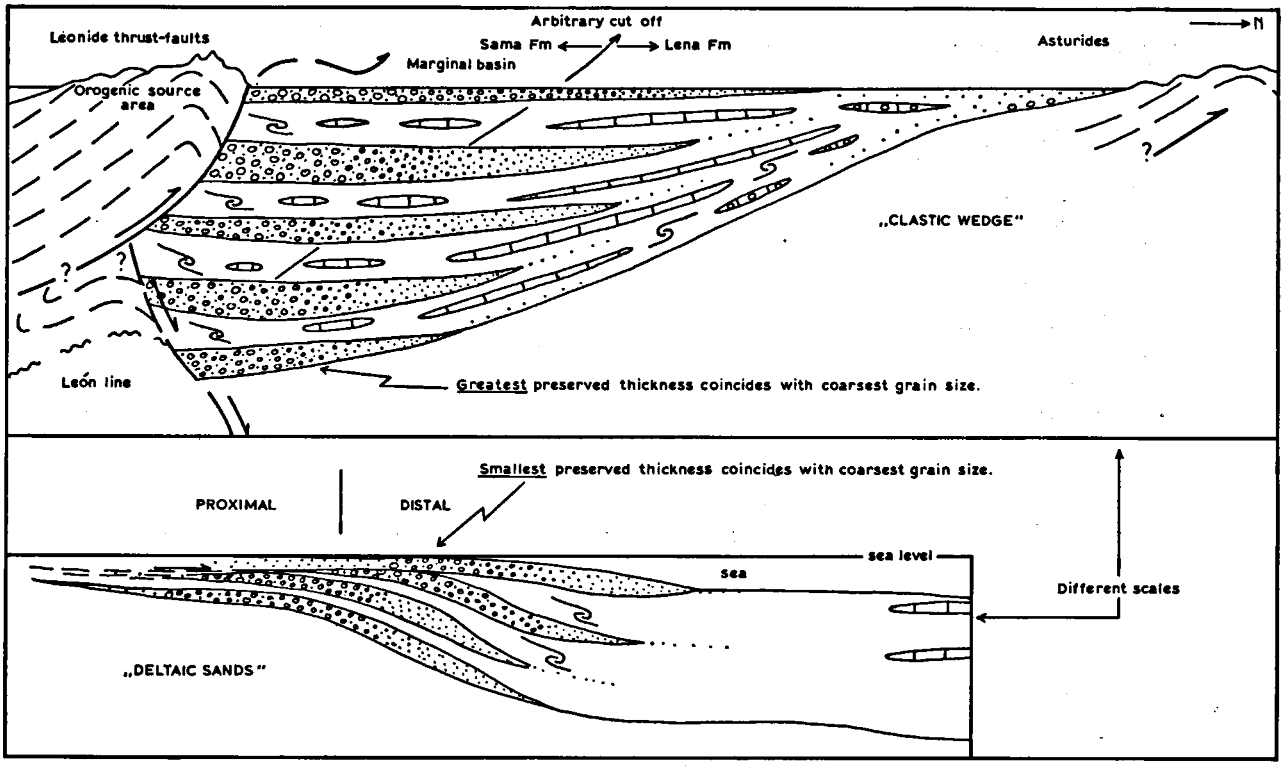

Fig. 30. Diagrammatic cross-section through the marginal Piedrafita Basin, north of the León line. The lower sketch is derived from Krumbein & Sloss (1963, p. 542) to illustrate the difference in geometry between clastic wedge and deltaic associations.

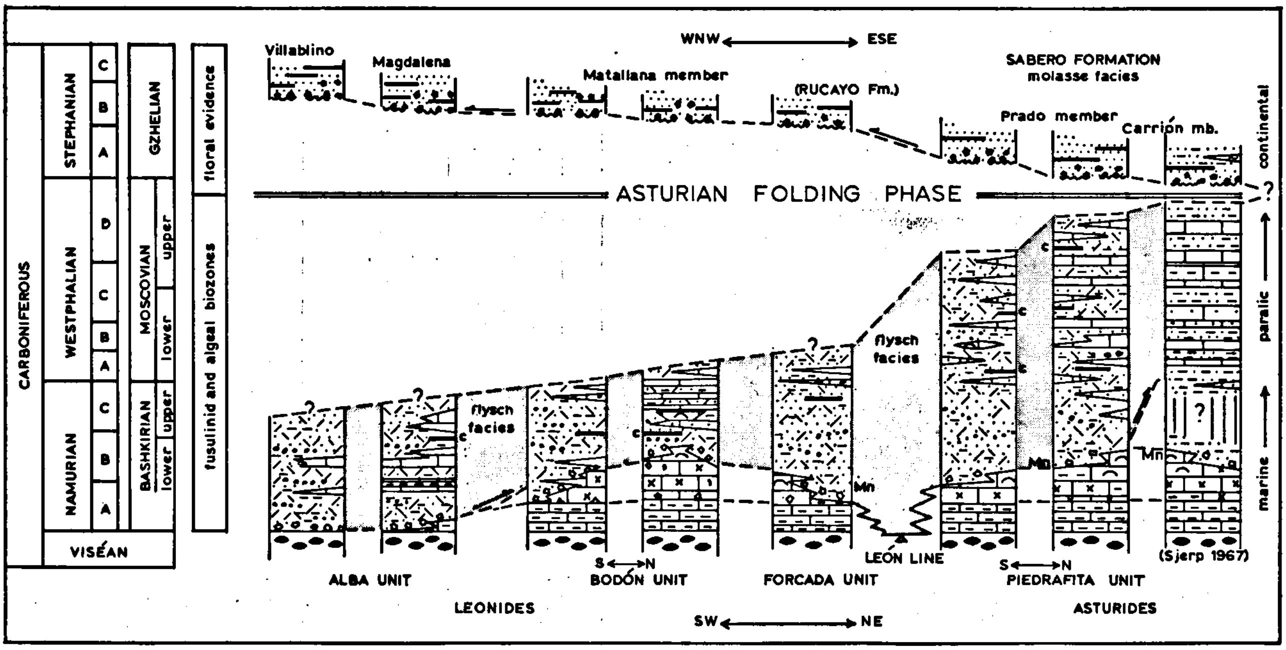

Fig. 31. Time-stratigraphic correlation of Upper Carboniferous, illustrating the migration in time and space of the flysch facies (from SW to NE) and molasse facies (from ESE to WNW).

Concluding Remarks

The description of the flysch facies illustrates the rapid lateral and vertical change in composition of the San Emiliano (fig. 24) and Lena Formations (fig. 30). Though one might be inclined to introduce different formal names for the flysch deposits in each tectonically restricted basin (for example, the Alba and Ferreras areas), this has not been done since it does not increase the interpretative value of the geological map. The use of the name Yuso Group is not possible in the present area.

As shown by the sections of figure 31 and appendix V, the San Emiliano and Lena Formations are partially synchronous deposits. No continuous differentiations could be mapped in the Lena Formation because here no unconformable (Curavacas) conglomerates were developed, and the Caliza Massiva or Escalada Formation disappears towards the southern flank of the Piedrafita Basin. On the provisional geological map of the southern slope of the Cantabrian Mountains (de Sitter, 1962), the basal mudstone member was coloured light blue (= San Emiliano Formation) in contrast to the brown colour (= Lena Formation) on Sjerp's map of the San Isidro-Porma area.

The large total thickness of the San Emiliano Formation (< 800 m) and the Lena Formation (< 2700 m) is partly due to the lateral replacement of the three members measured in sections perpendicular to the basinal (E-W) trend of the Carmenes and Piedrafita basins (figs. 24 and 30). The depositional patterns of the tectofacies were probably conditioned by the thrust-folding, which gradually shifted the axis of these asymmetric marginal basins. The subsequent narrowing of the basins in front of the upthrusts caused sub-marine slumping along the steepened flanks. As sketched in figure 30, the coarsest grain sizes in the "clastic wedge" are concentrated in the southern flanks, marginal to the emerging upthrusts. Tectonism was not short-lived, but migrated in time and space; gradually climaxing towards the Upper Moscovian or Westphalian, which conspicuously only developed north of the León line.

Fig. 32. The northern flank of the Matallana Basin near Vegacervera de Torío, looking ESE. From left to right: the Correcilla, Galicia and Salón mountains.

B. Upper Carboniferous Molasse Facies

The molasse facies in the Matallana and Rucayo basins were deposited after the main Asturian folding phase (lower Westphalian D) and lie unconformably on previously folded and eroded strata in tectonically restricted, intramountainous basins. In the present area, two formations are distinguished:

1. Sabero Formation in the Matallana and Sabero basins.
2. Rucayo Formation deposited along the León line.

Sabero Formation (> 1000 m)

The "schistes houillers de Sabero" (Comte, 1959, p. 334) consist of fan and torrential conglomerates, coarse to fine-grained micaceous sandstones, greywackes, carbonaceous mudstones and coal beds. The type area near the village of Sabero was first described by Ezquerra de Bayo (1844) and still represents the most thoroughly studied succession. Helmig (1965, p. 116) described the surface outcrops and underground sections from mines in the Sabero Basin. He found a 1000—1500 m thick succession (Prado member) ranging in age from the lower Stephanian A to the Stephanian B (fig. 31). The lithology of the Prado member (Sabero Basin) and the Matallana member (Matallana Basin) of the Sabero Formation is com-

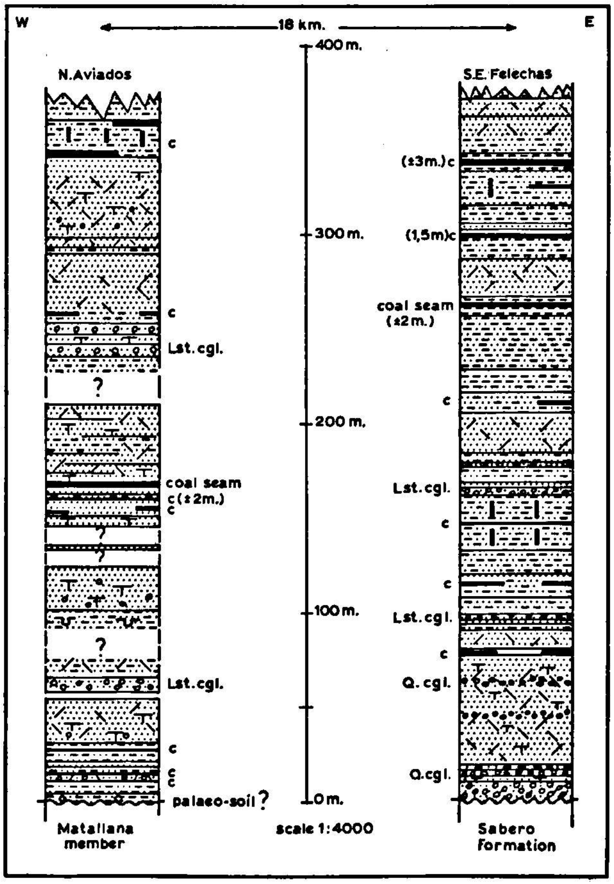

Fig. 33. Columnar sections of the Prado and Matallana members of the Sabero Formation.

parable (fig. 33), but the direct connection between these basins remains conjectural (Almela, 1949).
Eleven columnar sections were measured by Van Amerom (unpublished report) of which the most representative section (I), north of Aviados, is reproduced with few alterations in figure 33. In the less disturbed northern flank of the Matallana Basin (fig. 32), a partly lateral transition was recorded from the basal succession (ca. 500 m) of argillaceous sandstones, greywackes and torrential limestone conglomerates (fig. 34) to a uniform sequence (> 750 m) of lenticular mudstones, greywackes and coal beds. Towards the central part of the limnic basin, the coal seams increase in thickness and number.

Fig. 34. Torrential conglomerate in the basal part of the Matallana member near Vegacervera.

The unconformity below the Matallana member is poorly exposed and distorted. Locally, solution holes filled with red earth were noted below the terrestrial erosion surface which is overlain by a palaeo-soil of yellowish-brown mudstones.
The thick conglomerates (> 200 m thick) at the base of the Matallana member around Correcillas (fig. 54), consist of sub-angular limestone boulders and pebbles intercalated by better rounded quartz pebbles and sandstone lenses. The synsedimentary character of the E-W running fault south of Correcillas is shown by the unconformable cover of its western prolongation. Other examples of locally derived limestone conglomerate fans related to upstanding ridges in the basement occur north of Aviados, Vegacervera and Coladilla, but are absent along the steeply faulted southern flank of the Matallana Basin. These conglomerates should not be regarded as basal or transgressive conglomerates, because they wedge out rapidly towards the south and are of limited lateral extension.
The torrential conglomerate beds (fig. 34) which occur higher in the section, change laterally into microconglomerates and coarse-grained greywackes. Towards the central part of the basin, these conglomerates contain an increasing amount of better rounded quartz pebbles. The dimensions, good rounding and bad sorting of the quartz conglomerate lens as exposed in the Cueto Salón peak, suggest a longer distance from the northern source area or a reworking of older conglomerate beds.
In the upper part of the Matallana member, arenaceous shales and greywackes predominate. The grain size and iron-content decrease towards the center of the basin, while the colour of these limnic deposits becomes darker due to an increasing amount of micaceous and carbonaceous material.
Most coal seams in the central part of the basin are less than 2 m thick, but west of the Torío River the seams appear to be much thicker; Rivero (1945) even recorded seams of more than 15 m. The large thicknesses recorded in the Bardaya Mine north of Villalfeide, are partly due to tectonic disturbances in the eastern prolongation of the Aralla Fault, which locally forms the northern limit of the Valle sub-basin. Because the seat-earth of the lower coal beds is poorly developed, the question is raised whether the thick

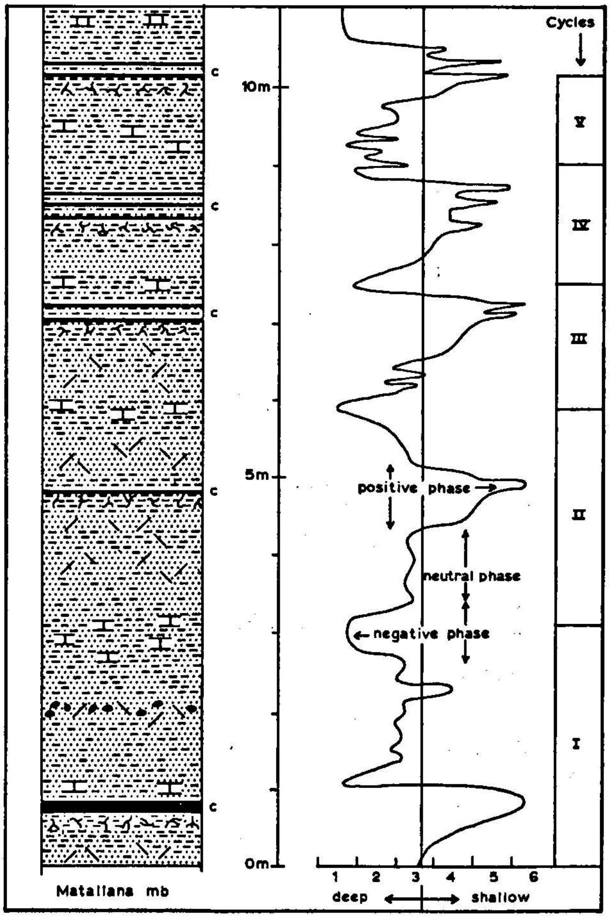

Fig. 35. A typical cyclothem of the Sabero Formation near Matallana.

coal seams are due to the accumulation of drifted vegetable material producing a lacustrine allochthonous sediment, or to an autochthonous peat in paludal environments.

Several laminated calcareous shale beds in the center of the basin yielded ostracods and lamellibranchs. These limy mudstone streaks (< 20 cm) form the base of small cyclothemes (ca. 1.5 m) which are found in all degrees of development (fig. 35).

1. "roofshales", with poor fauna
6. coal, with rich flora
5. "underclay" or carbonaceous shales
4. green arenaceous shales, iron concretions
3. sandstones and greywackes
2. grey arenaceous shales
1. dark blue, fine-grained, calcareous shales

These irregular alternations suggest pulsatory subsidence during short periods of rapid subsidence and longer periods of slow subsidence. After a relatively stable period of vegetational deposition (6), a sudden acceleration of the subsidence resulted in a water level too deep to permit further plant life. Limy mudstones (1) were then deposited before the rejuvenation of the relief in the source area is represented by torrential conglomerates or coarse-grained greywackes with sharp and occasionally angular basal contacts.

Several interesting sedimentological features such as scour-and-fill structures, load casts and ripple marks were recognized in the resistant sandstone beds (fig. 36). Current directions were measured by Van Amerom (int. rep.) by means of ripple marks, crossbedding structures, oblong plant fragments and especially moulds of lamellibranchs (*Anthraconauta* sp.) in combination with rill marks. His measurements show that the general current direction in the basal part of the northern flank of the Matallana Basin was towards the SW, while in the younger beds in the basin center, an E-W orientation prevailed.

The floral assemblages from the Matallana Basin were described in detail by Gomez de Llarena (1950, p. 76—78), who concluded a Stephanian A age. Wagner (1963, p. 86) discusses the age determination, which according to most specialized authors in recent years is Stephanian B. The reader is referred to publications on the palaeobotany of the Matallana Basin by Jongmans (1951, p. 294), Van Amerom & Van Dillewijn (1963, p. 308), Wagner (1963, p. 87; 1964) and Stockmans & Willière (1965, p. 79).

Fig. 36. Gullies in the greywacke and mudstone alternation of the Sabero Formation, E. of Matallana.

The fresh-water fauna was described by Texeira (1950, p. 102), Wagner (1963) and Van Ameron & Van Dillewijn (1963, p. 306), but the recorded ostracods, brachipods, lamellibranchs, crustacea, chaetopoda and myriapoda have little time-interpretative value.

Rucayo Formation (> 500 m)

The Rucayo Formation is introduced for the molasse deposits along the León line, which predominately consist of quartzite conglomerates with a few coal seams at the base. The type-section (fig. 37) was measured in the northern flank of the syncline east of Rucayo, where the thickest sequence was left by erosion.

The angular unconformity with the underlying folded and eroded strata is difficult to map, because later movements have often distorted the first disconformable beds. The basal part is composed of yellow and reddish

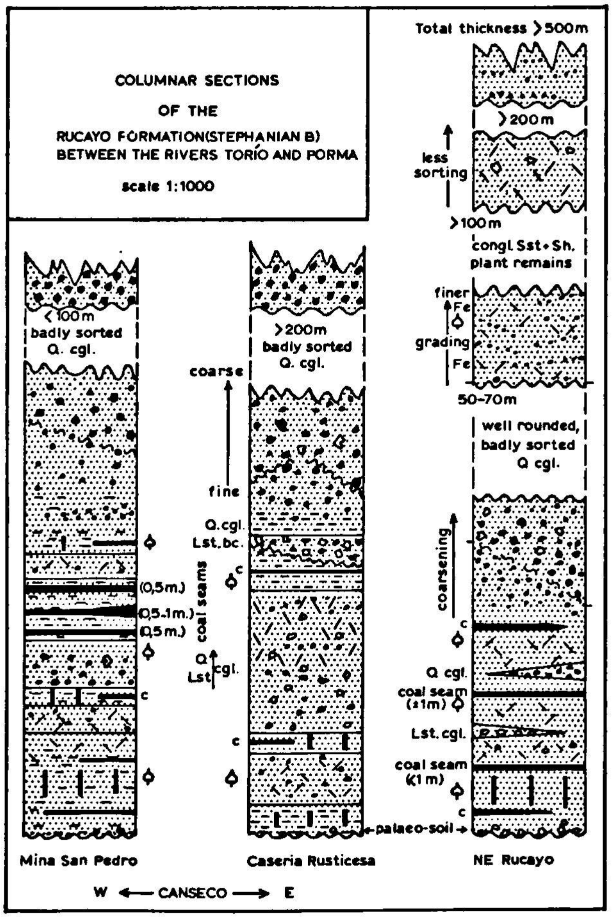

Fig. 37. Columnar sections of the Rucayo Formation.

brown mudstones with a few limestone conglomerate lenses. At several locations, coal is mined from seams with short lateral extensions. Wagner (1963, p. 109) and Van Amerom (1965a and in Sjerp, 1967, p. 97—100) collected floral assemblages from the tips of coal mines west of Canseco and east of Rucayo; both authors concluded a Stephanian B age. The thickness of the carbonaceous lower part of the Rucayo Formation can vary from less than 1 m to over 40 m W of Canseco (fig. 37).

The transition to the overlying quartzite conglomerates is often marked by paraconformable and angular contacts. The pebbles and boulders of these poorly sorted conglomerate banks are sub-angular to well-rounded. Towards the top of the Rucayo Formation, the pebble size decreases and gravels and coarse-grained sandstones prevail in the core of the basin. The total thickness of the Rucayo Formation in the type-section is over 500 m.

The possible evolution of the Matallana and Rucayo basins is sketched in figure 72; the restricted distribution in back and in front of the Leonide upthrusts is illustrated in figure 66.

UPPER CRETACEOUS AND TERTIARY

In the Upper Cretaceous and Tertiary deposits as exposed in the Porma Valley between Voznuevo and Candanedo, four predominantly coarse-grained terrigenous formations were recognised (fig. 38). The westward decreasing Upper Cretaceous limestone beds can be used as markers, since they are most resistant to weathering and fossiliferous. Rupke (1965) did not map formations, but tried to apply time-units, which should be avoided.

Ciry (1939) studied the Cretaceous and Tertiary in the area east of the Curueño River, he described the fossil assemblages of the Upper Cretaceous type-section between Voznuevo and Las Bodas. Almela (1949) studied the region between the Matallana and Sabero basins in search of a possible extension of the productive coal seams now covered by younger deposits. As an addition to his survey, two exploratory holes were drilled near Las Bodas and La Mata de la Riba.

The Upper Tertiary litho-facies units distinguished by Mabesoone (1959) in the province of Palencia are comparable to those in the area described here. Mr. A. A. Kuyp (Leiden) is preparing a detailed sedimentological study of the Paleogene rock units between the Bernesga and Esla rivers; he kindly provided useful information.

Voznuevo Formation (150—550 m)

This sandstone formation is named after the village of Voznuevo in the Porma Valley, 2 km E of Boñar. Along the road from Boñar to Colle, many exposures can be found in the clay and gravel pits in these gently south-dipping strata.

The multicoloured sandstones with lignitic clay and gravel lenses resemble the "Wealden" facies so strongly, that it is usually referred to by this name. The well-rounded quartz pebbles are generally coated purplish-red by a hematite film. Iron concentrations, lignite, large muscovite flakes, kaolinite and the vivid colours shading from white to purple, are the most characteristic features for fieldmapping. Due to rapid lateral

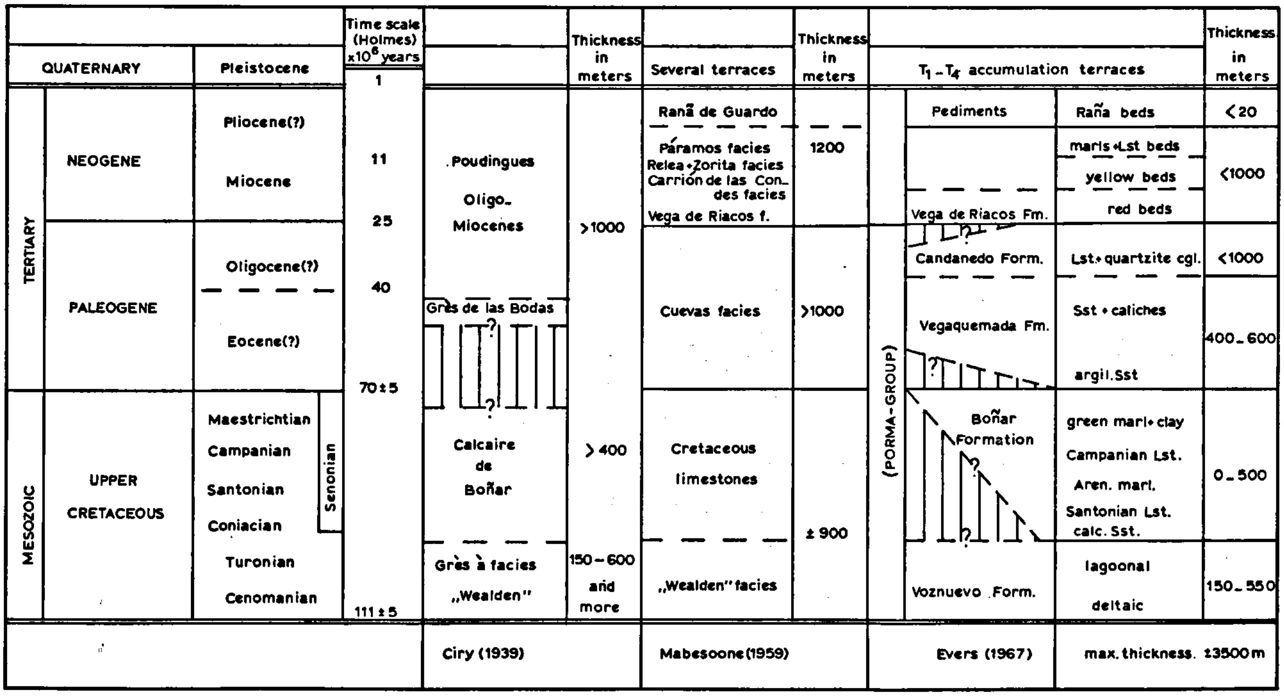

Fig. 38. Time-stratigraphic correlation of the Upper Cretaceous and Tertiary rock units in the NW part of the Duero Basin.

changes detailed sections of this formation are not representative for regional studies.

The Voznuevo Formation lies with a clear angular unconformity on intensively folded Palaeozoic rocks. The unconformity surface is usually flat indicating an advanced stage of peneplanation. A more pronounced erosional relief is found 1 km WNW of Voznuevo, where an alluvial fan conglomerate, consisting of rounded limestone and sandstone cobbles, was mapped. Sandstones and red ferruginous claystone lenses are intercalated in the flanks of the fan, which is about 1 km long and 80 m thick.

Approximately 200 m downstream from the Puente Romano over the Porma River, poorly sorted gravel and sandstone lenses are accumulated in typical deltaic fore-set beds showing inclined stratification. In the deltaic lower part (< 200 m), several allochthonous lignitic streaks (< 10 cm) occur. The wood-grain structures are well preserved, but occasionally the organic material is compressed to brown-coal. The upper part (200—400 m) of the Voznuevo Formation is composed of finer grained, micaceous sandstones with carbonaceous clay lenses, but gravel streaks still occur.

Van Amerom (1965b) determined pollen assemblages from the dark carbonaceous clay lenses in the upper part of the Voznuevo Formation north of Campohermoso and Palazuelo de Boñar; they indicate the lower part of the Upper Cretaceous, probably only the Cenomanian and Turonian. The recorded fresh-water algae and sedimentological properties point to a limnic depositional environment. The reworked and better sorted calcareous sandstones in the top of the formation indicate a higher wave-action in a lagoonal environment. These glauconitic sandstones, in which Ciry (1939, p. 40) found moulds of brackish water lamellibranchs, mark the advancing sea (Rat, 1959—1963).

Boñar Formation (0—500 m)

The Boñar Formation is composed of arenaceous limestones and marls. Due to the Cenomanian transgression which invaded from the east, the thickness, composition and age of these Upper Cretaceous deposits change gradually from east to west (fig. 39). The type-section was measured along the path from Voznuevo to Las Bodas; the village of Boñar is built on the western extension of these limestone cuestas.

Overlying the glauconitic transition zone, which according to Ciry might represent the top of the Coniacian in the Porma area, the following members are found from base to top.

a. Arenaceous marls and micaceous sandstones grading into coarse-grained, thickly bedded and well-cemented calcareous sandstones with yellow to reddish colours. Several layers rich in foraminifers, rudists and calcareous algae indicate a Santonian age and a shallow marine (epineritic) environment. Total thickness: 110—140 m.

b. An alternation of light-coloured limestones and arenaceous marls. Thickness: 50—60 m. The upper beds are composed of organic debris consisting of

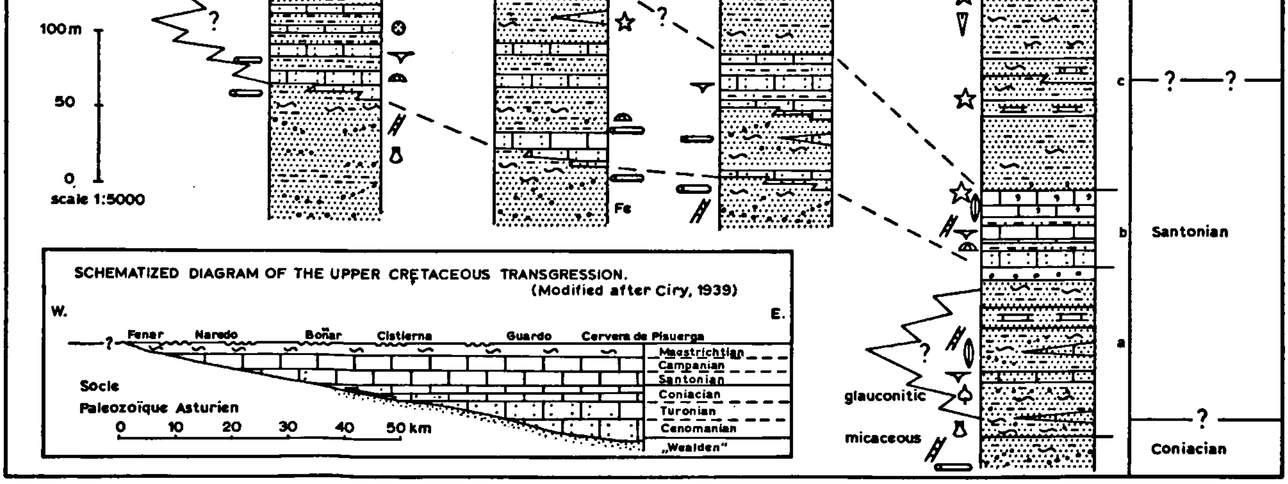

Fig. 39. Columnar sections of the Boñar Formation between the Bernesga and Porma rivers.

echinoids, rudists, foraminifers and green algae. Concentrations of large foraminifers (< 4 mm) give an oolitic appearance to some of these beds. A Santonian age was determined for this member.

c. Incompetent argillaceous sandstones grading into compact calcareous sandstones and arenaceous limestones. Thickness: 130—150 m. Lack of fossils makes age determination impossible.

d. Thickly bedded arenaceous and dolomitic limestones and sandy marls. The rich fauna (Ciry, 1939 p. 286—297) indicate a Campanian age. Total thickness: 50—90 m. Ciry divided this member into several beds, which are not representative over long distances due to lateral changes (fig. 39).

After the Upper Cretaceous transgression had ceased, variegated marls, sandy claystones and gravels developed in a typical "Garumnian" facies, marking the Maestrichtian regression (Gignoux, 1960, p. 467). The regression is locally caused by solution and shallow sub-aerial erosion in the upper limestone beds of the Boñar Formation. The gradual decrease of the total thickness towards the west is primarily due to the transgressive character of the formation and only to a small extent to the retreat of the sea and the subsequent abrasion and corrosion. The maximum thickness of the Boñar Formation in the present area was measured near La Devesa (ca. 480 m), near Boñar only 400—440 m is recorded; the western termination is visualized in figure 40.

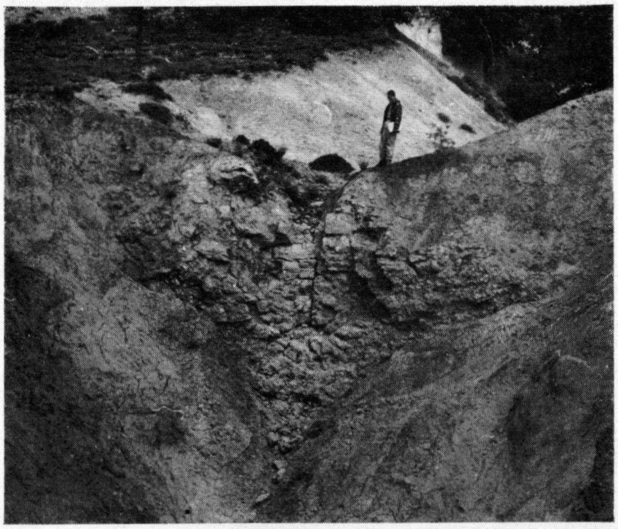

Fig. 40. The western-most exposure of the strongly reduced Boñar Limestone Formation, NW of Brugos de Fenar. Note the difference in colour (iron-content) between the Voznuevo and Vegaquemada Sandstone Formations.

Vegaquemada Formation (400—600 m)

The best exposure of these reddish sandstones is situated on the left bank of the Porma River, east of the village of Vegaquemada. The unconformity at the base of the Vegaquemada Formation is deduced from:

1. the basal zone with quartz pebbles resembling those from the Voznuevo Formation and with limestone fragments from the underlying Boñar Formation.
2. the undulating erosional surfaces with scour-and-fill structures.
3. the cavities in the top of the Boñar limestones filled with reddish sand grains.
4. the encroaching of the Vegaquemada Formation upon different limestone beds in the top of the Boñar Formation.

The lower part of the Vegaquemada Formation is formed by argillaceous sandstones (ca. 50 m), which contain a large amount of mica flakes, well-rounded and iron-coated quartz pebbles and several red unconsolidated clay lenses. During the Maestrichtian regression the Voznuevo and Boñar Formations were apparently eroded and redeposited at the base of the Vegaquemada Formation. Ciry (1939, p. 301) also noted the great resemblance between the lower part of the Vegaquemada Formation and his "grès à facies Wealden" (= Voznuevo Formation). He called these beds "Grès de Las Bodas" and in comparison with other areas assumed an Upper Eocene age and a small hiatus at the base of the formation (fig. 38).

A later uplift of the Cantabrian Mountains caused erosion and a greater inflow of terrestrial material than waves and currents could carry away, thus giving rise to a continental transgression of lagoonal deposits. The inferred inverse sedimentation (Birot, 1955, p. 105) is illustrated in figure 74. Some indurated beds of the Vegaquemada Formation are cemented by calcite; such "caliches" are generally due to the evaporation of lime-rich ground water during dry periods in a semi-arid climate with intermittent heavy precipitation (Mabesoone, 1959).

Towards the top of the Vegaquemada Formation, the sandstones become progressively coarser, while current-bedding structures and poor sorting are frequently observed in gravel lenses which were probably deposited in the alluvial fans of torrents descending from the rising mountain area. The total thickness and age of the unfossileferous Vegaquemada Formation is difficult to determine, but it is generally more than 500 m thick and is regarded as Paleogene.

Candanedo Formation (< 1000 m)

This formation is named after the village of Candanedo in the lower Porma Valley, where the limestone conglomerate beds are best exposed (fig. 41).

The transition from the Vegaquemada Formation is very gradual and therefore difficult to indicate precisely; the first thick limestone conglomerate bank is regarded as the base of the Candanedo Formation. In the lower part of the formation, the poorly sorted sub-angular limestone boulders may reach dimensions of nearly 1 m^3, but become smaller and more rounded towards the top of the formation. The matrix consists of coarse sand or gravelly material well-cemented by calcite. The thin red sandstone lenses that intercalate the thick limestone conglomerate banks mark the stratification (fig. 41).

Fig. 41. The gradual transition from the Vegaquemada Formation to the limestone conglomerate banks at the base of the Candanedo Formation. Note the flexure in the center of the Alobal Mountain, W. of Vegaquemada.

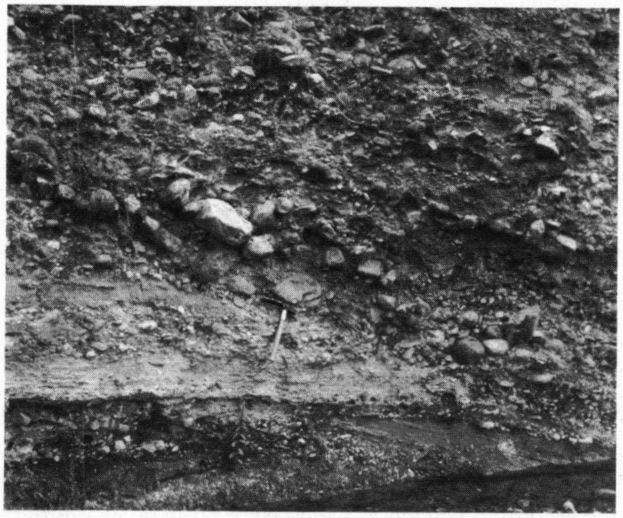

Fig. 42. Scour-and-fill structures and abrupt changes in pebble size at the base of the Candanedo Formation.

Interstratal erosion is indicated by channels cutting through several underlying strata and filled with finer-grained fluviatile deposits (fig. 42). These channels are probably due to the shifting courses of torrential rivers, but the continuous limestone boulder banks are best explained by a gravitational sliding mechanism of viscous masses down tectonically steepened sedimentary slopes, because the kinetic energy and load of torrential rivers are usually not great enough to transport such enormous limestone boulders over distances of more than 5 km.

The Piedmont conglomerate fans are typified by: 1. their great total thickness, 2. their persistent occurence parallel to the depositional strike and 3. the radiation from the point where the main rivers left the uplifted mountain area and spread out towards the basin center. The unusual conditions permitting the transportation of limestone boulders over large distances without being dissolved, might be due to a semi-arid climate with intermittent cloudbursts causing heavily loaded flash floods, or to the pulsatory uplift and subsequent erosion of the mountain ridge. A similar climate was deduced for the adjacent Vegaquemada and Vega de Riacos Formations containing "caliches" and red beds (Mabesoone, 1959 & 1962) and for the red sandstone lenses in the Candanedo Formation itself (Van Houten, 1961).

The frequency and dimensions of the boulders derived from the Boñar Formation decrease towards the top, while the proportion of Palaeozoic limestone and quartz-sandstone pebbles increases. Once the Piedmont deposition was no longer reactivated by a rising mountainous area, the erosion and the kinetic energy of the torrents decreased and broad floodplains with shifting rivers developed on top of the Candanedo Formation. The gradual transition to the post-morphogenetic, sub-horizontal "red beds" is recorded near Lugán (4 km S of Candanedo).

Near the foot of the mountain, the limestone conglomerates dip steeply due to post-depositional upheavals although the low dips in the southern part of the Porma section are primarily depositional. The coarsest components at the base of the Candanedo Formation coincide with the highest depositional dips and consequently, both pebble-size and dip decrease proportionally towards the basin center.

Most authors, such as Mabesoone and Ciry, propose a thickness of 1000 m for the limestone conglomerates but as indicated above, the thickness should not be measured perpendicular to the strike only, since the original dip of the outwedging piedmont fans was not horizontal. A lower value for the thickness is therefore assumed. The Vegaquemada and the Candanedo Formations are included in the Paleogene System without further differentiation into series, because no determinable fossils were found between the marine Upper Cretaceous and the overlying continental red and yellow beds which yielded remains of mammals and fresh-water molluscs indicating a Miocene age (Bataller & Sampelayo, 1944).

Most authors however, tend to include these deposits in the Oligocene and partly in the Lower Miocene, implying that at least the lower part of the Eocene is missing (fig. 38).

QUATERNARY

Several Quaternary geomorphologic features have been recorded at the foot of the Cantabrian Mountains by Birot & Solé Sabarís (1954), Nossin (1959), Mabesoone (1959) and many others, but in the present area few remnants are preserved.

The yellow and red, sub-angular quartz pebbles and boulders recorded in the thin (< 5 m) sub-horizontal sheets north of La Vecilla de Curueño (figs. 43 and 44) resemble those of the raña de Guardo (ca. 40 km E). The local derivation of the piedmont debris can be seen in their mountainous source areas of Lower Palaeozoic sandstones. The rañas (Oehme, 1936) are formed by sheet floods over a (Villafranchian) planation surface during a semi-arid climate with occasional heavy precipitation; compare Taillefer (1951).

Remnants of "high terraces" at a mean altitude of 1400 m in the upper courses of the Curueño and Torío rivers need more detailed study, as do the ground moraines with fluvio-glacial outwashes and the landslides in the area north of Lugueros and Pontedo de Torío. Glacial and pluvial phases during the Pleistocene (Würm glaciation according to Martínez, 1962) and renewed upheaval might explain the terraces in the sub-recent valley floors, which are usually 5—8 m above the present river level.

IGNEOUS ROCKS AND ORE DEPOSITS

Lower Palaeozoic igneous rocks

Several irregular intrusive bodies and stratified extrusive masses have been recognized in the Cambro-Ordovician clastic rocks of the Oville and Barrios Formations. These extensively altered and weathered dolerites and tuffites are difficult to map and therefore can be expected in even greater numbers than represented on the map. Winkler Prins (int.rep.) investigated these rocks in thin sections and found a relation between the dolerites and tuffites. His observations, used in the following description, agree in principle with those of Comte (1959), Garcia de Figuerola and Parga-Pondal (1964), Nollau (1965), Rupke (1965) and Sjerp (1967).

1. The dark green and brown dolerite sills (thickness: 10—100 m) prevail in the top of the Oville Formation. They can be traced with interruptions over considerable distances and were deformed together with their sedimentary wall rock.

A less altered olivine dolerite stock over 200 m in diameter is exposed in the Barrios Formation SE of Villamanin. The primary minerals — olivine, pyroxene and plagioclase — occur in the ratio 1 : 4 : 5. Apatite, titanite and rutile are the most frequent accessories.

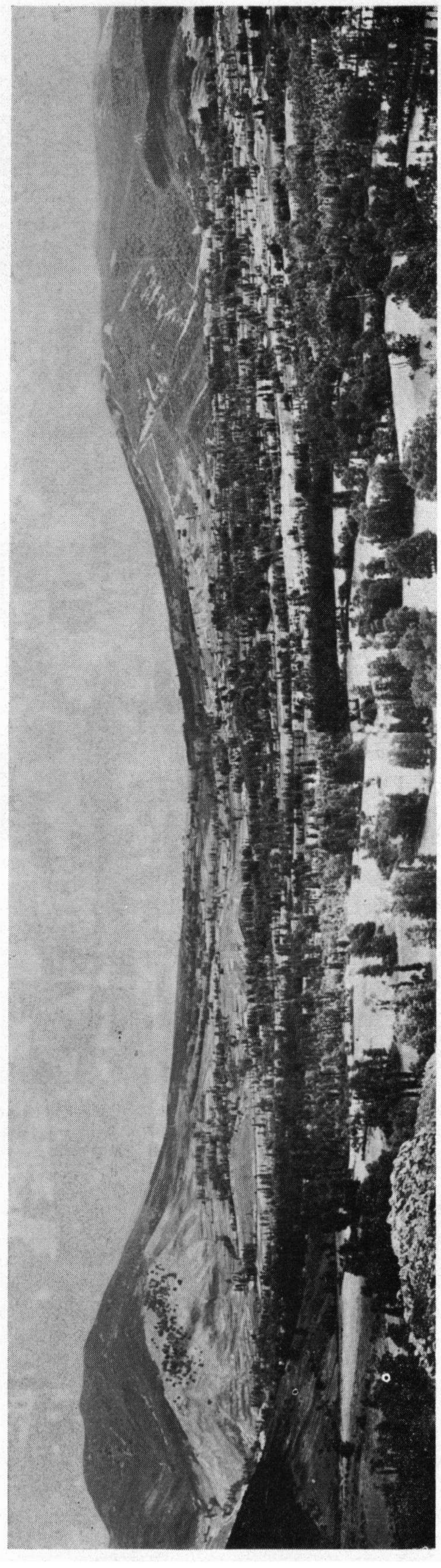

Fig. 43. The Curueño Valley between Valdepiélago and La Vecilla, looking east. At the left, the western extension of the Pardomino anticline with Herreria in the core. The Lancara Formation thrusts over the steeply folded Boñar Formation (Valdepiélago Fault). At the right, the south-dipping Candanedo Formation, in front and north of the pass to Boñar are raña fans.

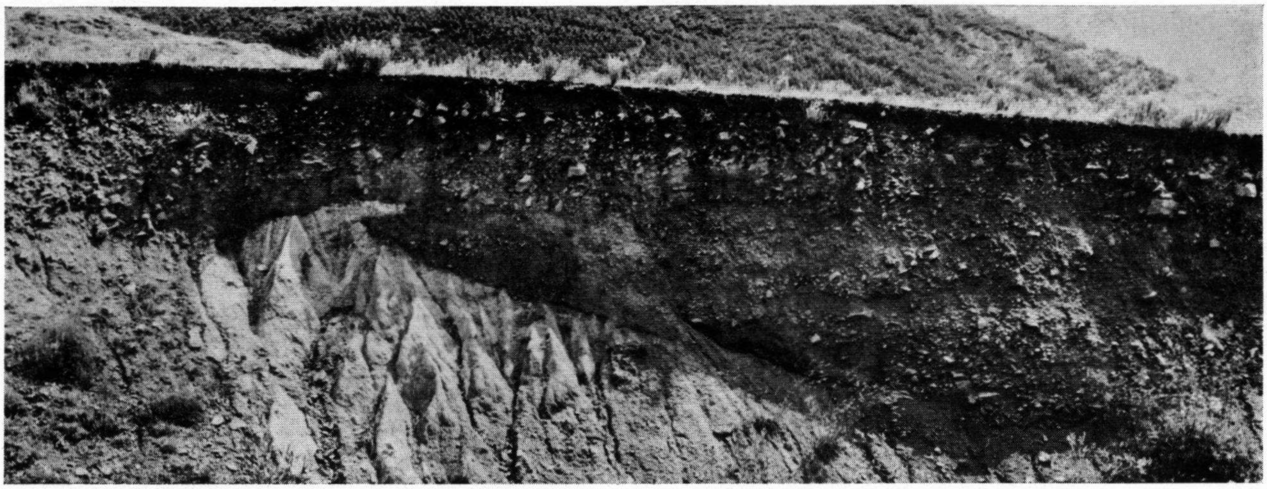

Fig. 44. Raña deposits on Vegaquemada sandstones, NW of Boñar. Note the flame structure, probably due to gravitational gliding; compare Nagtegaal (1966, fig. 9).

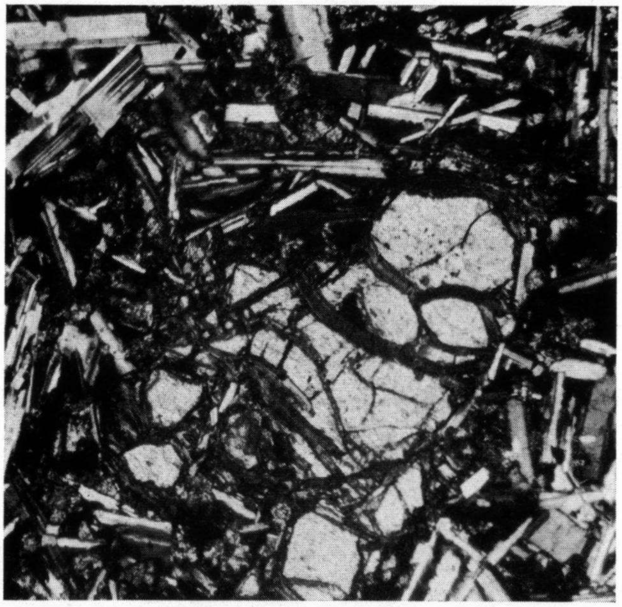

Fig. 45. Olivine phenocryst with mesh texture of serpentine, surrounded by augite and plagioclase (24 ×). Olivine dolerite stock SE of Villamanin.

The colourless, idiomorphic olivine crystals alter to serpentine, bowlingite, iddingsite and chlorophaeite; the typical mesh textures are, however, always recognizable (fig. 45). The colourless to light violet pyroxenes are diopsidic augites, with occasional rims of titan-augite; they are greatly altered to chlorite. The plagioclase (andesine-labradorite) decomposes to sericite and calcite; these plagioclase laths surround the mafic components and generally form an ophitic texture. The chemical composition of this olivine dolerite (V. 12) is: SiO_2 = 50.08, Al_2O_3 = 14.47, Fe_2O_3 = 1.92, FeO = 9.90, MnO = 0.13, MgO = 6.63, CaO = 8.79, Na_2O = 2.50, K_2O = 0.55, H_2O = 2.29; total = 99.39%.

A pyroxene-bearing gabbroic sill containing augite phenocrysts with a porphyritic texture was recorded SW of Genicera. A hydrothermal vein consisting of prehnite and pumpellyite in sferulitic aggregates was determined only in the large dolerite sill NW of Valdorria. Associated are albite, augite, pennine and apatite, while the ore minerals are partly converted to leucoxene.

According to Winkler Prins, the diopsidic character of the augite, the presence of andesine and the absence of contactmetamorphism might point to shallow and relatively cool dolerite intrusions under sub-marine conditions.

2. The pyroclastic rocks consist of stratified tuffites: grey if leucoxene-rich, green if chlorite-rich and purplish-brown if hematite-rich; they contain small bombs and many green and white lapilli (fig. 46). The dark green lapilli are composed of sferulitic chlorite

Fig. 46. Volcanic bomb and lapilli in a tuffite of the Barrios Formation.

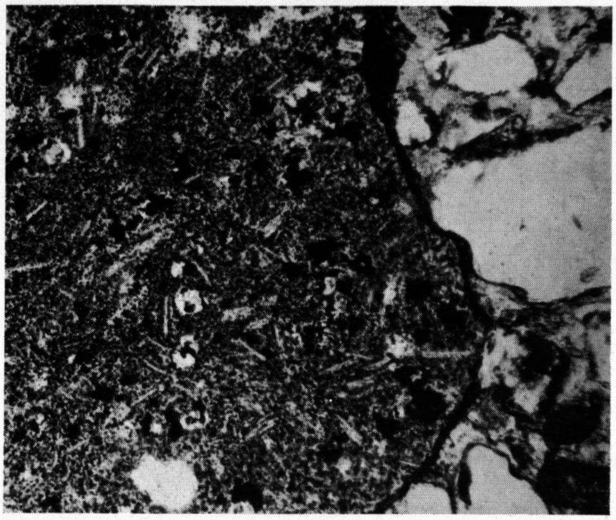

Fig. 47. Tuffite, mainly consisting of plagioclase laths and ore; from a pyroclastic section of the Oville Formation (60 ×).

with leucoxene and occasionally quartz and calcite. The white lapilli are composed of andesine laths in a fine-grained groundmass (fig. 47). The volcanic glass is devitrified. The amount of detritic and cementing material is often larger than that of the effusive particle in these tuffaceous sandstones.

3. In the purplish-brown hematitic sandstones of the San Pedro Formation (Upper Silurian) concentrations of lapilli with bright red vivid, green and white colours occur, but could not be mapped. In thin sections, these lapilli are also easily distinguished from the lapilli in the tuffites of the Oville and Barrios Formations since chlorite, plagioclase and leucoxene are absent and the light brown volcanic glass is not devitrified. Probably, the local volcanism was sub-aerial in contrast to the sub-marine extrusions of the Cambro-Ordovician.

Ore deposits

The following ore deposits were mined before the civil war, but had to be abandoned in recent years:

1. psilomelane and goethite, in irregular concentrations in the Barrios Formation SW of Villamanin.

2. hematite, in concentrations of 17—46% Fe_2O_3 in the San Pedro Formation. In open pits SE of Villamanin, up to 61% Fe_2O_3 and $< 1\%$ FeO were determined. The P_2O_5 content varies in proportion to the hematite content from 0.2 to 3%. Chemical analyses by Mr. K. M. Stephan, Petrochemical Laboratory of the Geological and Mineralogical Institute, Leiden University.

3. barite, along the fault contacts in the eastern extension of the Aralla fault zone, N of Vegacervera.

4. galenite and sfalerite with cerussite and greenockite, in the dolomitized Caliza de Montaña Formation SE of Velilla de la Tércia, conspicuously restricted to silicified mylonite zones.

5. cinnabar, in the argillaceous limestones of the San Emiliano Formation, E of Almuzara.

6. villamaninite, chalcopyrite, dark- and light- coloured linneite, pyrite, marcasite, bravoite and, less abundant, tetraedrite and cobaltine are the primary minerals in the "La Providencia" mine, W of Villanueva del Pontedo. In the cementation zone of the strongly dolomitized Caliza de Montaña Formation occur: bornite, chalcocite and covelline, while limonite, malachite and azurite occur in the oxidation zone. Large quantities of copper and iron were also mined from the "La Profunda" mine, 4 km NW of Cármenes; unimportant deposits occur S of Tolibia and SE of Valdehuesa.

The "La Providencia" mine is the only locality in the world where villamaninite $(Cu, Ni, Co, Fe).(S, Se)_2$ has been found. Schoeller and Powell (1920) described it for the first time, but the best determinations were given by P. Ramdohr (1937—1960). The weight percentages of the main elements constituting this black mineral are: Cu = 17.6—22.1%, Ni = 15.9—18.2%, Co = 6.3—7.4% and Fe = 4.2—6.0%.

It occurs as cubic crystals and sferulitic aggregates (diameter $< \frac{1}{2}$ cm), which are mainly replaced by chalcopyrite, linneite and bravoite (fig. 48). Recent studies by Hey (1962) and Dr. P. J. M. Ypma and Mr. E. E. H. Rijks (Leiden, pers.comm.) suggest that villamaninite might in fact be composed of two minerals. Moreover, the primary minerals appear to be stratigraphically restricted to the (euxinic?) micrite member of the Caliza de Montaña Formation. The primary minerals (4—6) in the Lower Carboniferous limestones are regarded as low temperature, epithermal mineralizations, which are probably related to intrusions along the fundamental fault zones, as exposed in the area around Riaño. In the present area, however, no Carboniferous intrusions have been mapped.

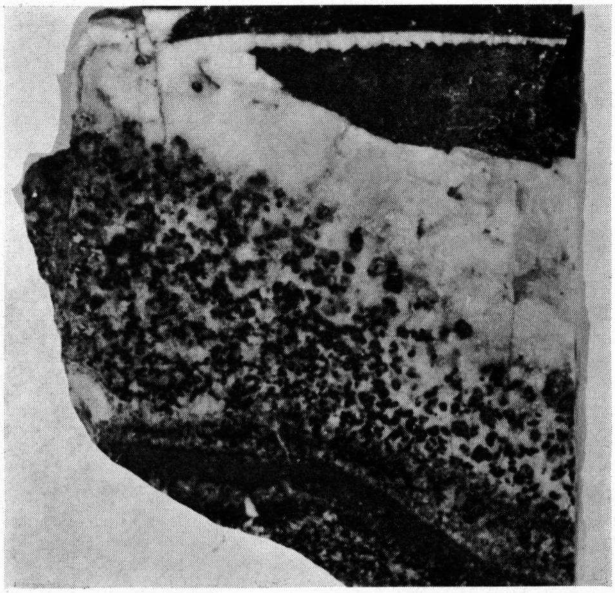

Fig. 48. Villamaninite cristals in a calcite vein from the La Providencia mine, NW of Cármenes. (2 ×).

CHAPTER II

STRUCTURES

INTRODUCTION

The most important structures in the Bernesga-Torío-Curueño-Porma area and in the related structural sections are first analysed geometrically in the order listed below:

A. Leonides
  1. Pardomino
  2. Alba & Corada
  3. Esla
  4. Bregón
  5. Pozo
  6. Rozo
  7. Correcilla
  8. Gayo
  9. Bodón
  10. Forcada

B. Asturides
  11. Ferreras
  12. Piedrafita

C. Molasse Basins
  13. Matallana
  14. Rucayo

D. Mountain Flexure Zone
  15. Ollas

In the kinematic and mechanic analyses, the amount and direction of displacement due to the following tectonic deformations is described:

1. Hercynian Period

a. Bretonic epeirogenic phase; during the Upper Devonian and Lower Carboniferous
b. Sudetic initial folding phase; during the Namurian.
c. Asturian orogenic phase; during the Westphalian.
d. Saalic late-orogenic phase; during the Stephanian.

2. Alpine Period

e. Savian morphogenetic phase; during the Paleogene.

As described in the stratigraphic analysis most of these phases are marked by erosion periods, basal conglomerates or syntectonic deposition of tectofacies: e.g. flysch, molasse and pediments in marginal basins. In the back-pocket of this paper are:

1. a geological map with index map.
2. eight S-N cross-sections, perpendicular to most structures.
3. a structural fold-model illustrating the interference of the two main axial trends.

The fold-model (app. VI) also illustrates the small ($< 3°$) deviations between the true and apparent dips, due to projection of the normally steep ($> 70°$) dips on the composite S-N cross-sections, which approximately lie on 65° angles with the prevailing WSW-ESE trends.

GEOMETRIC ANALYSIS

A. Leonides

The Leonides are situated south of the León line (de Sitter, 1962); they consist of an autochthonous and a thrust fold zone. The thrust fold zone of the Central Leonides is located between the Sabero-Gordón hinge line and the León line. The Leonides are divided by the WSW-ENE trending Pardomino Ridge, the autochthonous zone which is accentuated by the Porma Fault. The relatively large Esla thrust unit and associated structures have been described by Rupke (1965); the seven upthrusts west of the Porma Fault form the main subject of the present study (structural index map and fig. 14).

The allochthonous areas are partly covered by late- and post-orogenic molasse basins, which conspicuously were deposited in the backtrough area (Matallana and Sabero basins) or in front of the upthrusts, marking the León line (Rucayo Basin) (fig. 66).

1. Pardomino Unit

The mountains north of Boñar consist of a WSW-ENE anticlinorium with the Cambrian Herreria Formation at the core and limited in the north by the remarkably straight Porma Fault. The Lancara Formation can be traced from the NE "root zone" of Primajas to Cerecedo and further west to Valdepiélago, where a comparable "root zone" of thrust folds was mapped. The nearly complete succession of Lower Palaeozoic and Devonian rocks below the Esla "Nappe" has been called "the autochthone of Valdoré" by Rupke (1965, p. 45), although these rock units show considerable thrusting and are now in a north-overturned position. The Precambrian basement does not crop out, but is expected to have acted as a fundamental "high" with approximately the same dimensions as the present Pardomino Ridge.

In the western extension of the Pardomino Ridge around the Pico Cueto, a steeply plunging anticlinal structure has developed where the Porma Fault ends. The fold axis plunges steeply towards the ENE, thus forming a synform (Fleuty, 1964). Further west, it regains its proper anticlinal appearance since the fold axis plunges with decreasing steepness towards the WSW. Small strike faults in the uniform Herreria sandstones could not be mapped over large distances, but might explain the extensive Herreria outcrop.

The southern flank of the Pardomino anticlinorium is overturned and generally dips 60°—70° NNW, but west of Cerecedo 20°—30° NNW dipping strata occur. The bordering Valdepiélago Fault brings the crushed and partly mylonitised Lancara Formation in contact with subsequently folded Cretaceous and Paleogene rock units.

2. *Alba and Corada Units*

The broad and intricately folded Alba and Corada synclinoria resemble each other in their stratigraphic and tectonic properties. Though partly covered by younger deposits, they may be regarded as one WNW-ESE striking synclinorium, essentially south of the fundamental Sabero-Gordón line. These units represent the area of maximal subsidence during the Upper Devonian and earliest development of flysch facies — instead of Caliza de Montaña limestones — on top of the Visean griottes (fig. 31).

The Sabero-Gordón Fault was reactivated in the Paleogene and can therefore be traced from the western extension of the Corada Unit to the eastern end of the Alba Unit and from Aviados further west to La Pola de Gordón. This fault zone is marked by normal or reversed faults which are partly covered by Stephanian and by superficial thrust-folding in the steeply south-dipping, northern flanks of the disharmonically folded basins.

Detailed mapping in the complicated area west of Aviados revealed at least two more or less continuous, E-W trending faults. The sharply folded Santa Lucia Formation in the Peña Mountain clearly shows the broken asymmetric folds. The less competent La Vid and Huergas Formations apparently acted as local detachment planes, because the upthrusts bring Santa Lucia and Portilla limestones in fault contact with younger beds.

The broken anticlinal structures in the Peña can be correlated with the Mirantes anticline. The synclinal structure in the Caliza de Montaña Formation north of Aviados probably represents the eastern prolongation of the Pedroso syncline WNW of La Pola de Gordón (see structural index map).

The upthrust NE of San Adrian detached at the base of the Huergas Formation and over a long distance marks the southern border of the Sabero Basin (Casetas Fault; Helmig, 1965, p. 134). The reversed fault south of Las Bodas can also be traced further east; it represents the La Llama Fault, which brought the Sabero Formation in fault contact with Upper Cretaceous and Paleogene rock units.

3. *Esla Unit*

Only a small portion of the Esla Unit is exposed north of Voznuevo, because its western extension is covered by Upper Cretaceous (section 7). Like most thrust units in the Leonides, the Esla thrust fault detached the base of the Lancara Formation from the more competent, thick Herreria Sandstone Formation which unconformably overlies the rigid Precambrian "basement". The black shales and marls at the top of the Herreria Formation acted as a lubricant due to their incompetent character and the large contrast in competence with the adjacent strata. As often observed along the fault planes of large overthrusts, hardly any disturbances or tectonic breccias occur.

The fault contact with the Huergas Formation is sharp and regular. Further east, younger Devonian and even Carboniferous rocks crop out below the thrust plane; this suggests the upcutting in the front of the thrust fault and consequent termination of the Esla Unit towards the west. The dip (ca. 70° NNW) of the Lancara Formation and the underlying Devonian strata are approximately the same.

4. *Bregón Unit*

The southernmost thrust unit in the Leonides west of the Pardomino Ridge is named after the Bregón Mountain, 1 km west of Ciñera. The anticlinal axis

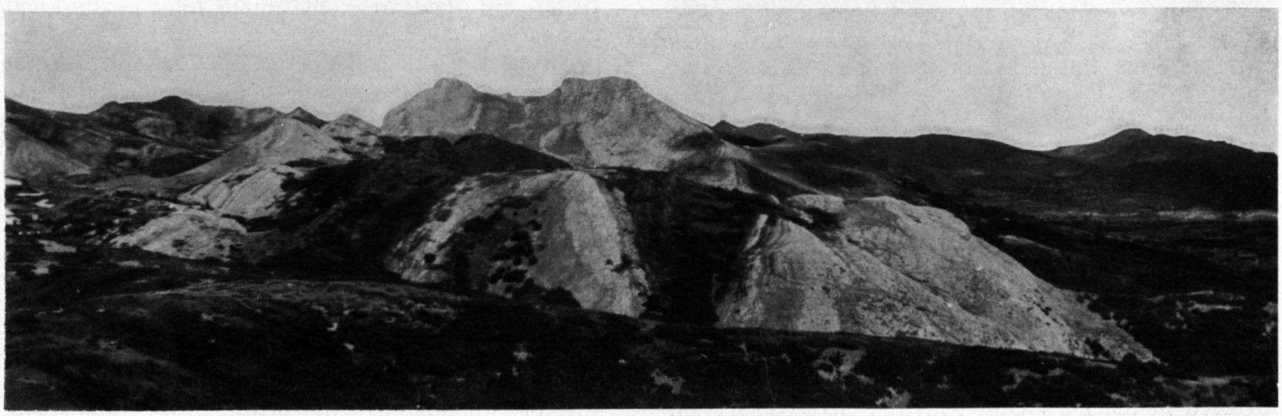

Fig. 49. The western extension of the Montuerto synline N of Aviados, covered by Stephanian molasse facies (in front). At the back, the Peña Galicia (Santa Lucia Formation). Note the reduction of the Huergas Formation towards the south.

merges with the eastward upthrusting fault which ultimately brings the steeply north-dipping Lancara Formation on top of the Huergas Formation. Further east the Bregón Unit is cut off by a normal fault and covered by the Stephanian Matallana Basin.

The stratigraphic and tectonic relation of the Bregón Unit with the underlying Huergas Formation supports the assumption that its eastern prolongation reappears in the center of the Montuerto syncline north of Aviados. In the southern flank of this syncline a gradually thinner Huergas section was mapped (fig. 49). In cross-section 4, the assumed downcutting of the Bregón thrust fault into the Devonian strata is shown. The rootzone can be expected less than 2 km further south along the Sabero-Gordón hinge line, but is now covered by Stephanian. A possible connection between the comparable Bregón and Esla Units remains conjectural.

5. *Pozo Unit*

In front of the Bregón Unit another roughly WNW-ESE trending upthrust could be traced from its anticlinal western termination in the Pico del Pozo (NW of La Vid) to its eastern root zone near Valdepiélago. After an interruption due to the Matallana Basin, the Pozo thrust fault reappears east of Correcillas and is refolded in the broad WSW-ENE Montuerto syncline (fig. 50).

Fig. 50. The Montuerto syncline looking west. Taken from the Prado Llano with the Peña Galicia in the back.

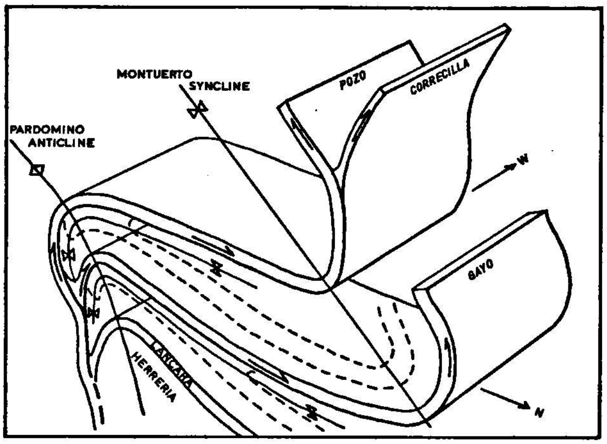

Fig. 51. Diagrammatic sketch of the Pardomino anticline and Montuerto syncline in the Curueño Valley.

The northern flank of the Montuerto syncline dips approximately 80° NNW while the southern flank gradually flattens from sub-vertical to less than 40° NNW. West of the Curueño River, the synclinal fold axis gradually plunges less steeply towards the WSW. The same phenomenon is found in the flat anticline south of the Peña Galicia. The southern prolongation of the Pozo Unit is obscured by the Matallana Basin and later faulting, but by tracing the basal Lancara Formation further east and comparing the rock units involved in the Pozo Unit with the Cerecedo section below the Esla Unit, a correlation appears most probable. Section 5 illustrates the rapid downcutting of the Pozo thrust fault through the underlying Gayo Unit until the hinge-contact with the basal Lancara Formation is reached in the complicated root zone between Montuerto and La Mata de la Berbula (fig. 51).

The Pozo Unit normally has the Lancara Formation at its base and is topped by the Huergas Formation. Apparently, a good thrust plane existed at the disconformity surface near the top of the Devonian. The maximal exposed thickness of the rock units involved in the Pozo Unit is over 1400 m.

The basal Lancara and Oville Formations are disharmonically folded and locally brecciated; small silicified mylonite and barite outcrops mark the thrust plane NW of Vegacervera and Valdepiélago.

The less competent Oville, Formigoso and La Vid Formations are strongly deformed; they were squeezed out near the sharp bend of the competent Barrios Formation in the Peña del Pozo. The Oville shale-sandstone alternations in the anticlinal core of the thrust folds are deformed disharmonically, as a result of the repeated compression from different (induced) directions. Several parasitic minor folds related to larger folds in thicker sandstone layers and frictional drag folds with steeply plunging fold axes occur.

In less disturbed areas, the minor folds in the Oville Formation have more regular geometric properties persisting along the axial plane (fig. 52). Some of these parallel folds have straight limbs of unequal length with sharp and partially broken anticlinal edges. They resemble the chevron folds as described by de Sitter (1956, p. 216).

6. *Rozo Unit*

The eastern extension of the Rozo Unit is developed as a complicated syncline cut off by the Pozo thrust fault. The fold axes of the Villasimpliz syncline and the broken Pozo anticline plunge less than 60° WNW. From the point where the Correcilla Unit originates (W of Villamanin), the Rozo thrust fault bends sharply SE and the thrust movement is taken over by the Pozo thrust fault. The Rozo Unit is the main

Fig. 52. Chevron folds in the Oville Formation.

thrust fold unit west of the Bernesga River and has been studied by my colleague Van Staalduinen (in prep.).

7. *Correcilla Unit*

The central Correcilla Unit consists of a 1700—1900 m thick succession of Lancara up to Caliza de Montaña Formations folded in a broad synclinorium. The variation in thickness (roughly 200 m) is due to the decrease in the Upper Devonian hiatus from the northern Sancena culmination to the southern flank of the Valporquero syncline. The relatively small thrust fold in the SW corner of the Correcilla Unit is composed of a WNW-ESE syncline and a broken anticline, which are incorporated in the main Correcilla Unit. The variably plunging anticlinal axis gives rise to three separate culminations with Barrios quartzite at the core. The best exposure of the bordering thrust fault is in the Formigoso Valley and again N of Valle de Vegacervera (section 2).

The Correcilla Unit can be regarded as a frontal offshoot of the Rozo and Pozo Units; the hinge contacts are exposed W of Villamanin and E of Valdorria. The line between these points approximately represents the WNW-ESE trend of the initial thrust-folding, which is also seen in the western extension of the main syncline. The dip of the inverted northern flank of this syncline is 70°—80° NNE, while the intricately folded southern flank dips only 30°—40° NNE. The minor folds have flanks of unequal length; the flat northern limbs are usually more than twice as long as the steep southern limbs of the anticlines.

Similar large and small-scale "zig-zag" folding patterns (Wilson, 1951, p. 399) are even more clearly exposed in the eastern extension of this synclinorium around the Correcilla Mountain, where steep erosion produced an excellent location for studying the flat structures three-dimensionally (figs. 53 and 54). The shale member of the La Vid Formation clearly acted as a very incompetent layer, responding only partially to

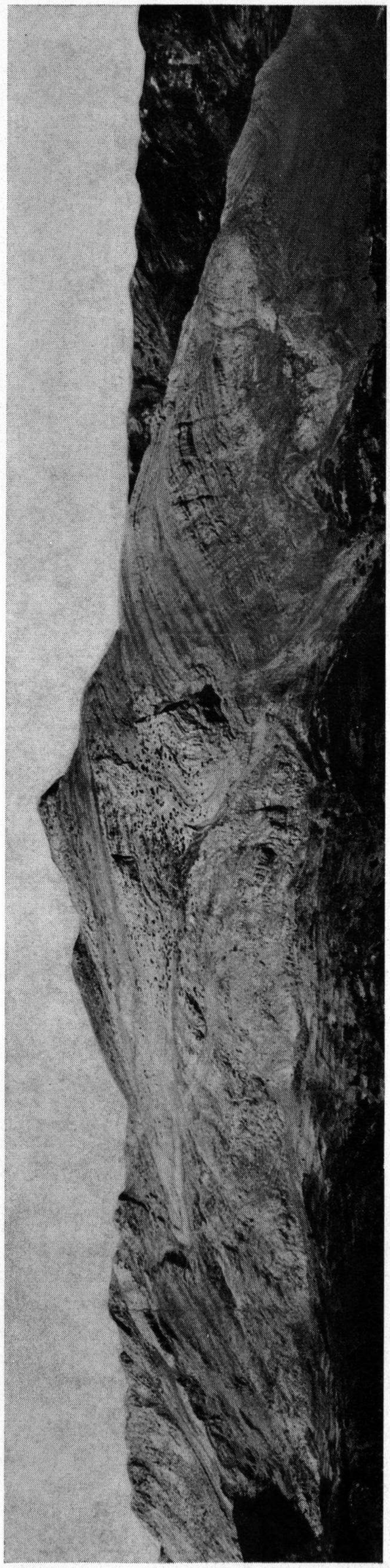

Fig. 53. Recumbent folds in the Correcilla Mountain, looking north. In front, the unconformable cover of molasse deposits in the northern flank of the Matallana Basin.

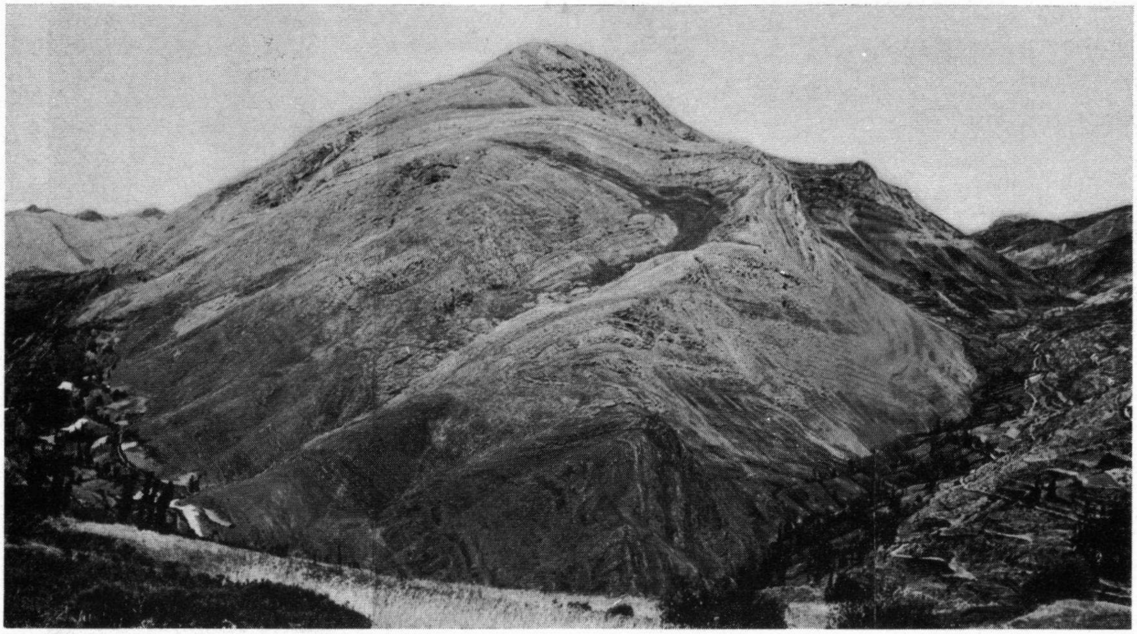

Fig. 54. Recumbent folds in the Santa Lucia and Caliza de Montaña Formations in the Correcilla Mountain (2000 m), looking WNW. The darker, hardly folded strata at the base represent the western extension of the limestone conglomerate fan at the base of the Stephanian Sabero Formation.

the folding of the adjacent competent beds which are folded much more sharply above than below the shale member. In the sharp synclinal bend of the competent Santa Lucia Formation 4 km west of Valporquero de Torío, the La Vid shales were squeezed out. A superficial thrust fault in the La Vid Formation was difficult to map in the Rodillazo Valley, but a good vertical section is exposed east of Felmin.

In front of the great anticline in the Barrios Formation another syncline with Caliza de Montaña limestones in the center is exposed in the Sancena Mountains. Between Valdorria and Gete, the Correcilla thrust fault bends towards the north and while cutting up through the Lancara to Santa Lucia Formation, overrides the San Emiliano Formation in the back of the Gayo Unit (sections 3, 4 and 8).

8. *Gayo Unit*

The root zone of the Gayo thrust fold, where the basal Lancara Formation detaches from the Pardomino (par-)autochthone, is located NE of Valdepiélago. The hinge syncline between Valdepiélago and Montuerto is difficult to recognise due to later refolding and subsequent digitations in the western extension of the Porma Fault. The prolongation of the Gayo thrust fault is encountered 5 km further ENE along the straight Porma Fault near Valdecastillos, where the basal Lancara and Oville Formations are repeatedly folded and thrusted in front of the Porma Fault. The Gayo Fault cuts through the strata in the small southern flank of the syncline in front. Several mylonitized zones occur near Valdecastillo and in the disharmonically folded Barrios orthoquartzites north of Valdepiélago. Another brecciated and recrystallized zone is exposed E of Montuerto, where the Gayo thrust fault ultimately cuts through the Caliza de Montaña Formation and thrusts over the less resistant San Emiliano Formation.

The total thickness of the rock units involved in the Gayo Unit is over 1700 m (fig. 64). The exposed width of the roughly WNW-ESE trending Gayo thrust fault is about 30 km, measured from Valdecastillo to Velilla de la Tércia where a sharp anticlinal bend and associated tear faults mark its western extension (section 2). The Gayo thrust fault and overlying strata are generally inverted, dipping sharply northwards. The anticlinal fold axis near Velilla plunges sharply west and at the core even changes from subvertical to overturned to the east. The subvertical dip of the thrust fault can also be inferred from the map: a stratigraphical succession of about 1700 m is cut off by the Gayo thrust fault over a horizontal distance of only about 2 km.

The considerable internal stress which accompanied the sharp anticlinal bend is also expressed by the splay of tear faults and tectonic breccias. Friction along the fault planes was obviously so high that a 1500 m long and 10 to 30 m wide silicified ultramylonite "dike" was formed, consisting of a structureless glassy rock mass in which few angular orthoquartzite and silicified limestone fragments can still be recognized. In the brecciated and partly silicified and dolomitized Caliza de Montaña Formation, several mineralizations like galenite and sfalerite were mined along the faults.

Similar mylonites have been recorded along the Gayo thrust fault: near Golpejar, west of Valverde, Valdeteja and Valdecastillo. The NE-SW trending faults south of Carmenes are clearly post-thrustfolding, because they displace the Gayo and even the Correcilla thrust faults.

9. *Bodón Unit*

In contrast with the other upthrusts in the Leonides, the broad Bodón Unit has probably been detached at the base of the Herreria Formation, where the greatest contrast in competence can be expected between the Precambrian basement and the overlying sedimentary rocks. The eastern root zone of the Bodón Unit is located 5 km NE of Valdecastillo just in front of the Porma Fault (see Rupke, 1965); the western prolongation has been mapped by Van Staalduinen (in prep.).

The Bodón Unit is 1900—2300 m thick and over 40 km long; it is folded into the broad Montuerto syncline, the Valdehuesa anticline and the La Venta syncline, which are further accentuated by faults. The axial plunge of these structures remains very steep to the WSW throughout the Z-shaped flexure.

In the western extension of the Bodón Unit north of Millaró, the thrust fault starts to cut up through the Lower Palaeozoic succession. In this area, the Bodón Unit is in fault contact with the Westphalian Lena Formation and eventually forms the northern limit of the Leonides. West of Millaró, the condensed La Vid Formation decreases in thickness as a result of the Upper Devonian hiatus, but near the "La Providencia" mine, the San Pedro to Alba Formations are cut off by a fault of uncertain dimensions. Between this mine and south of Llamazares, the fault runs parallel to the base of the Caliza de Montaña Formation and probably also to the Upper Devonian erosion surface which is expected to run at approximately the same level in the Oville Formation as in the Forcada Unit.

There are two places in the southern flank of the Carmenes syncline where the increase in Upper Devonian hiatus can also be recorded: 1. at the restricted exposure of La Vid shales SW of Carmenes, which can be correlated with a comparable gap in the

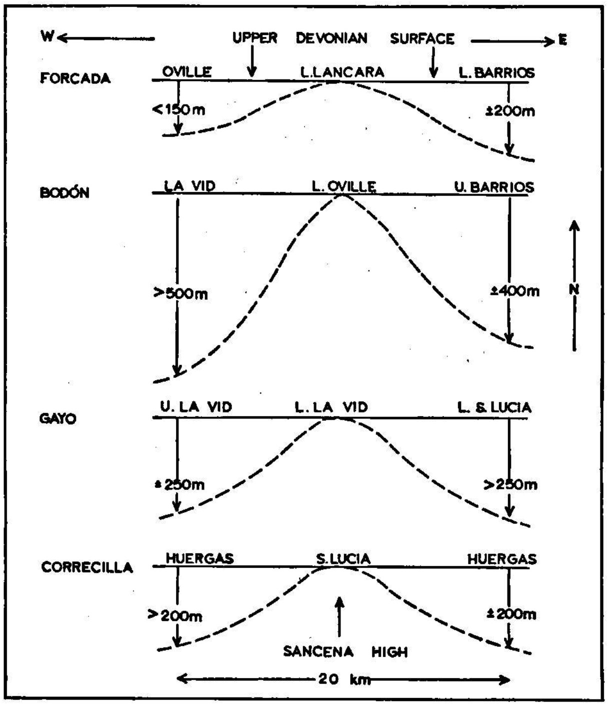

Fig. 55. The Sancena High as deduced from the E-W variation in Upper Devonian hiatus in the four northern thrust units (S-N).

Fig. 56. The sharply folded San Emiliano Formation near Barrio de la Tércia. Note the rapid variations in thickness of the limestone beds. In front, the steeply west-dipping anticline in the western extension of the Gayo Unit; at the back, large screes from the moundlike structures is the top of the Caliza de Montaña Formation (Bodón Unit).

adjacent Gayo and Bodón Units and 2. at the Barrios outcrop west of Valdeteja, which equals the Upper Devonian erosion level recorded in the northern flank of the Carmenes syncline around La Venta. The absence of the Barrios up to La Vid Formations between these locations implies a gap of more than 500 m in less than 10 km, or a local E-W gradient of 50 m per km. This gap clearly marks the Sancena High (fig. 55), which retarded the onlap of the Lower Carboniferous transgressions (fig. 23) and probably facilitated the faulting between La Providencia and La Venta.

Another important fault zone was mapped in the southern margin of the Carmenes syncline, between Valdeteja and Golpejar. The so-called Valdeteja Fault is also marked by silicified mylonite lenses and mineralizations; it appears to be associated with the Gayo thrust fault and influenced the asymmetric basin configuration (cross sections 1—4).

The disharmonic character of the Carmenes synclinorium (fig. 56) is partly due to refolding, which gave rise to variably plunging fault axes and culminations like the one SW of Carmenes. The axial planes of the asymmetric folds in the Carmenes synclinorium dip 60° NNE.

10. Forcada Unit

The stratigraphic sequence in the northernmost Forcada Unit is only 500—800 m thick. The elimination of the competent Barrios Formation greatly influenced the asymmetric folding and ultimate thrusting. The Forcada Unit is more than 30 km long, measured from the western extension SW of Campo to the eastern root zone in front of the Porma Fault, 7 km NE of Valdecastillo (see index map and Rupke, 1965).

Between Valdehuesa and Rucayo, several digitations from the thrust fault mark the front of the Forcada Unit, which is partly thrusted over the flysch deposits in the marginal Ferreras area, and partly thrusted against the Stephanian B molasse deposits in the Rucayo Basin. The refolding of the Forcada Unit in this area is mainly due to late-tectonic normal and wrench faulting along the major Valdehuesa and Solle faults (fig. 68).

Around Tolibia de Arriba and west of Canseco, the Upper Devonian hiatus eventually eliminated the Lancara Formation which usually marks the base of the Forcada Unit. Since the Lower Carboniferous Vegamián and Alba Formations are also absent here, the Forcada thrust fault runs at the base of the Caliza de Montaña Formation. West of Canseco, however, this formation tends to become lenticular and even disappears (app. V); consequently, the continued upcutting of the thrust fault runs through the San Emiliano Formation. The fault contact between the flysch facies of the San Emiliano and Lena Formations is difficult to map and in addition is locally covered by the unconformable Rucayo Formation.

The small reapperance of Alba griottes in front of the Bodón thrust fault SE of Aviados and SW of Redilluera mark the small dimension of the southern flank of the syncline in the back of the Forcada Unit (section 3).

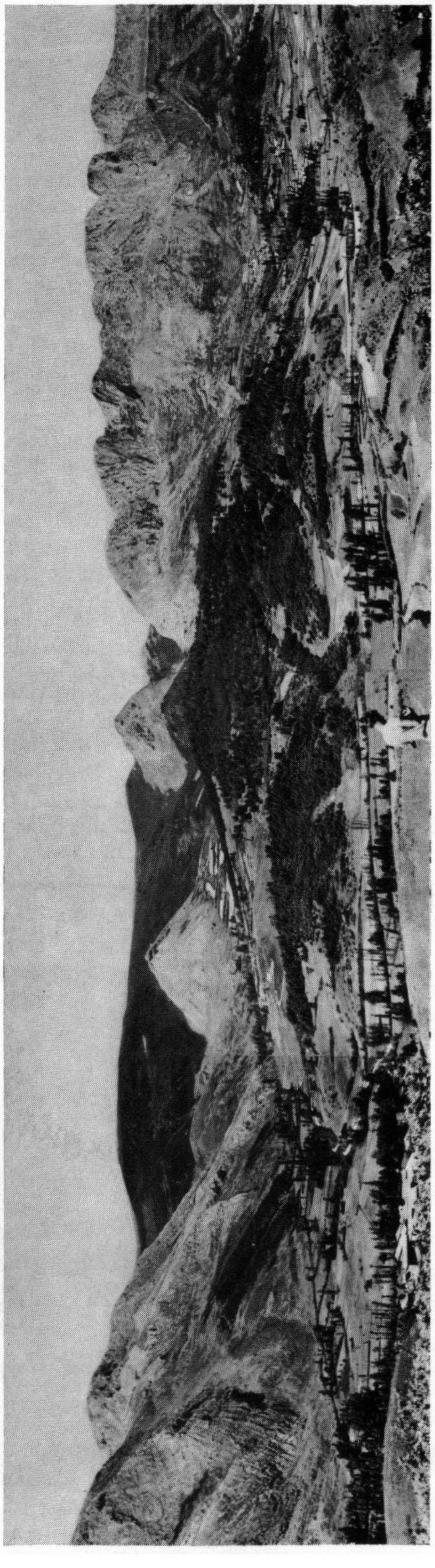

Fig. 57. The broken Valdehuesa anticline in the Forcada Unit, which partly overthrusts the flysch deposits in the Ferreras area. Photo taken from the hills near Campillo, looking WSW.

The longer northern flank of the thrust fold is intricately folded in a set of zig-zag folds which make the Caliza de Montaña Formation appear much thicker, especially S of Canseco and NE of Arintero.

B. Asturides

11. The Ferreras Unit

The litho- and bio-stratigraphic analysis of the Ferreras area has shown that it represents the southern flank of the marginal Piedrafita Basin in front of the Leonide upthrusts and the Valdehuesa Fault. It consists of a coarse-grained succession of flysch facies, paraconformably overlying the steep north-dipping Caliza de Montaña as exposed S of Lodares. Fusulinids in the gradually more abundant limestone lenses (see app. V) and top-and-bottom criteria indicate a decreasing age of the succession northwards (Namurian-Upper Moscovian). Only minor folds were recorded in the central part of the Ferreras area, but near the Forcada thrust fault and especially along the Valdehuesa fault zone (fig. 57) the Lena Formation is tectonically disturbed. Some parasitic folds appear to have formed before the consolidation of the strata.

In the tunnel west of Ferreras, a three-dimensional picture of the thrust fault contact of the Forcada Unit with the Lena Formation could be studied. The fault plane and the barely deformed Lancara Formation dip 67° WSW; the underlying flysch deposits are so crumpled that no reliable measurements could be made. The general trend of the greywacke and limestone lenses shows a gradual bending towards the NW in front of the Forcada Unit, but as shown in sections 6 and 8, a certain amount of overthrusting is interpreted from the map, since the southern flank of the Piedrafita Basin does not reappear west of Ferreras. The gravity survey in this area also indicates a "low", which extends further west (fig. 75).

12. Piedrafita Unit

The stratigraphic analysis of the Westphalian flysch deposits in the Piedrafita Unit revealed the asymmetry of the WNW-ESE trending marginal basin (app. V and fig. 30). The greatest subsidence took place in front of the Leonides east of Canseco, where the youngest fusulinid assemblages (Upper Moscovian) were recorded. The asymmetric folding was towards the central axis of subsidence, resulting in north-dipping axial planes. The total thickness of the Lena Formation increases westwards and consequently, most fold axes plunge variably towards the west. The limestone beds decrease and the coarse-grained greywacke beds increase in thickness and number towards the southern flank of the basin; such an irregular distribution of the most competent beds strongly influenced the disharmonic folding of the Lena Formation. The main structures in the Piedrafita Unit are related to the major E-W folds in the Lower Palaeozoic "basement", as exposed in the eastern margin of the basin, mapped by Sjerp (1967).

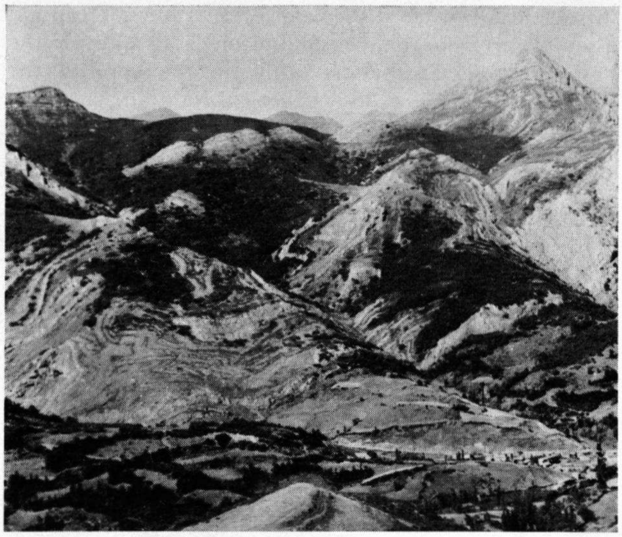

Fig. 58. Complicated anticlinal structures in the limestone member of the Lena Formation, north of Rucayo. At the left, the Aparejo Mountain; at the right, the Susarón Mountain.

The north-dipping axial planes are difficult to trace over long distances due to the poor degree of exposure, the absence of continuous markers and the disharmonic mode of deformation further complicated by the steep topography.

As shown in figure 58, most structures in the Piedrafita Unit are more complicated than could be drawn according to the map scale. The closed structures on the map are mainly due to the steep topography and, to a lesser extent, to cross-folding resulting in differently plunging fold axes.

In the NE corner of the map, two roughly WNW plunging anticlinal and synclinal fold axes are exposed

Fig. 59. Disharmonic folding of the Lena Formation in the Piedrafita Basin, N of Lugueros. Photo looking west, shows a broken cascade fold.

in the thickly bedded to massive limestones. Fusulinid assemblages from these basal limstone beds indicate the base of the Westphalian, while in the core of the synclinal structure in the Aparejo Mountain, a nearly completed succession up to the Upper Moscovian or Westphalian C is exposed.

The disharmonic folding of the Lena Formation is best exposed in the Curueño Valley north of Lugueros (fig. 59), where reflected images of the anticlinal and synclinal structures on both sides of the valley could be correlated over considerable distances. The roughly E-W striking axial planes dip steeply northwards, but the fold axes plunge less steeply towards the west. The long, 30° to 60° N dipping northern flanks of the major anticlines are less complicated than the inverted, 70° N dipping southern flanks in which cascade folds and oblique shear faults have been recorded (fig. 70). Completely inverted middle limbs of cascade folds have been recorded in the structurally higher sections between Lugueros and Cerulleda and between Campo and Piedrafita in the Torío Valley. The competent beds are locally detached resulting in disharmonic and divergent folding above the fault plane; the slip was basin-inwards.

As illustrated in figure 71, the minor folds in the northern flank are of the chevron or zig-zag type (de Sitter, 1964, p. 301), while the minor folds in the inverted southern flank represent parasitic folds. A slaty cleavage parallel to or somewhat flatter than the bedding is developed in the argillaceous beds. The cleavage curves towards the competent beds (fig. 60), but was never found in the concentrically folded greywackes and limestones. A similar kind of slaty cleavage is recorded in the parasitic folds of the overturned southern flanks of the anticlines N of Campo and Lugueros. The basin-inwards directed shearing movement has stretched the bedding plane and flattened the argillaceous layers (de Sitter, 1958). This is visible in the boudinage structures (fig. 60a) in the competent beds of the Lena Formation. The shearing is also shown in these thin sections by the approximately 70° left lateral rotation of the quartz crystal in the calcite vein. According to Van Ginkel (written comm.), the form-ratio of a central-oblique section of the *Bradyina* sp. in this thin section should be nearly one, but is now elongated.

C. Molasse Basins

13. Matallana Unit

The asymmetric Matallana Coal Basin is situated in the "back trough" zone of the Leonide upthrusts and mainly in front of the Sabero-Gordón Fault zone, which was also active during and after the sedimentation of these late-tectonic molasse beds (figs. 66 and 72). The basin configuration and the major synclinal structures are therefore mainly related to these faults in the basement.

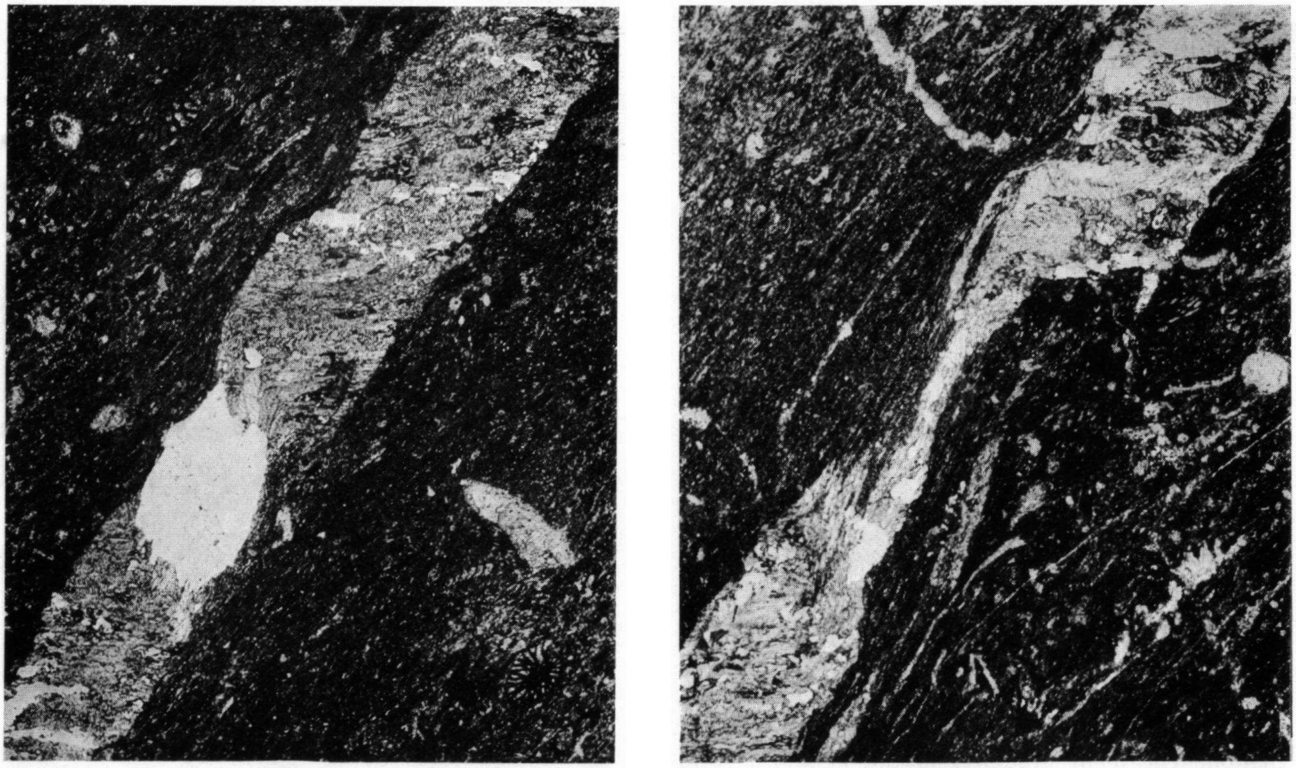

Fig. 60. Slaty cleavage in calcareous shales of the Lena Formation, north of Campo (25 ×). The confining pressure caused the elongation of the foraminifers (a) and a shear movement along the calcite vein resulted in boudinage (b). The quartz cristal in fig. 60a has probably been rotated (Zwart, 1962).

The best exposure and least complicated example of synsedimentary faulting was mapped south of Correcillas, where torrential limestone conglomerates at the base of the Sabero Formation are folded in a sharp syncline and cut off by an E-W trending fault. The steeply west-plunging fold axis is eccentrically located just in front of the fault. Westwards, the syncline becomes progressively flatter and ultimately disappears, while younger conglomerate beds and coal seams are undisturbed by faulting and can be traced further south. In these structurally higher sections only minor flexures parallel to the basin configuration occur, but they also disappear as one proceeds basin-inwards.

The main Matallana syncline is much more complicated, because it is limited by the Gordón Fault zone which was reactivated after the deposition of the Stephanian B. The southern flank of the E-W trending syncline dips steeply to the north and locally, even inverted strata and upthrusts were recorded in front of this fault zone.

The youngest floral assemblages are found SW of Serilla in the center of the main syncline whose fold axis merges with a fault in the structurally lower sections further east. No important tectonic deformations or upthrusts have been recorded in the long northern flank of the basin, which dips approximately 40° S in the center and 70° S in the northern border areas. Only irregular parasitic folds of limited dimensions occur in the less competent mudstones between the thickly bedded greywacke lenses (fig. 61).

Fig. 61. Parasitic folds in the northern flank of the Matallana Basin, E of Vegacervera.

North of Aviados and Vegacervera, several parasitic minor folds with variably plunging fold axes were recorded at the base of the Matallana member. The upthrusts in the Bardaya Mine are most probably related to the eastern extension of the reactivated Aralla (fault) zone.

The Coladilla and Valle de Vegacervera sub-basins were also influenced by the syn-depositional Aralla and Ciñera faults, which later accentuated the synclinal structures. The crumpling and ultimate downcutting of the coal seams NE and SW of Villar del Puerto and east of Ciñera illustrates that these faults were also active after the deposition of the Matallana member, but probably before the rocks were fully lithified.

14. The Rucayo Unit

The western prolongation of the Rucayo Basin is developed as a shallow, less than 800 m broad depression in front of the Forcada upthrust. East of Rucayo and west of Canseco, a sharply folded synclinal structure could be mapped, but normally the stratification in the Rucayo Unit is distorted and even the partly broken unconformable contact between the molasse and the underlying flysch deposits is difficult to map. The southern boundary of the Rucayo Unit is usually marked by the Forcada thrust fault, but tectonically disturbed unconformities were mapped around Lugueros. Compaction could not play an important role in the structural setting since only the thin lower part consists of mudstones and a few coal seams, while the bulk of the Rucayo Formation is composed of poorly sorted quartz conglomerates.

D. Mountain Flexure Zone

15. Ollas Unit

The roughly E-W trending southern border of the Cantabrian Mountains is typified by a subvertical to overturned fault contact between the Palaeozoic core and its Upper Cretaceous cover. As shown in the structural index map, the area around Barrio de las Ollas represents a break in this trend since faults associated with the Alpine mountain flexuring preserved the Upper Cretaceous at higher latitudes. The stratigraphic analysis has revealed that the most pronounced morphogenetic uplift occurred during the Upper Oligocene to Lower Miocene — corresponding to the Savian phase of Stille (1924).

In the WSW-ENE trending flexure-zone from Naredo to Campohermoso, the south-dipping strata near the faulted unconformity surface become gradually steeper and are even overturned, dipping about 80° NNW (cross-sections 3 and 4). The influence of the mountain flank thrusting rapidly decreases towards the south where flat, continental deposits typify the center of the León marginal basin (fig. 74). The depth to the "basement", the dip of the fault plane and the position of the second step-fault in the cross-sections are deduced from the geological map and the gravity profiles (fig. 76).

Between the Curueño and Porma rivers, a more complicated structural setting due to the reactivation of the important Sabero-Gordón Fault is found (fig. 62). The reversed faulting in the Palaeozoic basement gave

Fig. 62. The Valdepiélago Fault and associated structures in the Ollas Unit. Photo looking SE, over the Curueño Valley.

rise to the asymmetric San Adrian anticline and Las Bodas syncline in the overlying rock units (cross-sections 5—7). The broken northern flank of the WNW-ESE trending anticline dips progressively steeper (45°—80° N) in the structurally lower parts east of La Mata de la Riba. The southern flank of the anticline dips gently (30°—40°) SW, but east of La Devesa the strata again become progressively steeper due to the flexuring and fold-thrusting recorded near Cistierna (Rupke, 1965, p. 68).

The asymmetric Las Bodas syncline eccentricatel) located in front of the La Llama Fault (Helmig, 1965, p. 134) belonging to the Sabero-Gordón line, has a steep north-dipping and even inverted southern flank and a 25°—40° SSW dipping northern flank. NW of Barrio de las Ollas, the flat northern flank is abruptly disturbed by the variably north-dipping Valdepiélago Fault, which thrusted the southern flank of the back-folded Pardomino anticline on top of the younger strata (fig. 62). The limestone beds of the Boñar Formation north of Ranedo and Barrio de las Ollas disappear below the Palaeozoic rocks over an E-W distance of nearly 5 km. The fold axes of the subsequent disharmonic folds plunge sharply ($< 60°$) towards the central depression.

The construction of the Cretaceous layers in the southern part of cross-sections 6 and 7 was partly derived from the gravity profiles (fig. 76) and checked with data from drill holes near La Mata de la Riba and Las Bodas (Zalona & Sampelayo, 1943). The assumed source area of the partly syntectonic limestone conglomerates is drawn "in the air".

KINEMATIC AND MECHANICAL ANALYSIS

1. Hercynian Period

a. Bretonic phase

The stratigraphic analysis of the Lower Palaeozoic, and more specifically the Lower Devonian, has revealed minor differences in thickness and facies in the shelf area south of the fundamental León line (fig. 14). During the Upper Devonian however, more pronounced differentiations into positive and negative areas become apparent. The León line is marked by the area of greatest Upper Devonian hiatus and the Sabero-Gordón line appears for the first time as the hinge line between a northern area of uplift and progressively deeper denudation, and an area of continued subsidence and rapid accumulation south of this line. The fundamental Pardomino line separates the Leonides into a Bernesga-Porma area of large tilt (ca. 4° SSW) and an Esla area of small tilt (ca. 1° SSE?) which was mapped by Rupke (1965, p. 39). The palaeogeographic maps (figures 15 and 16) and composite sections (fig. 14, app. III and IV) illustrate the regional WNW-ESE trend of the Leonide facies and the fundamental León and Sabero-Gordón lines. They also show the position of the Bernesga and Esla sub-basins separated by the WSW-ENE trending Pardomino Ridge. The three fundamental tectonic lines were active before the main Hercynian deformation and were repeatedly reactivated afterwards. They form the facies boundaries and likewise controled the folding process, which appears to be directed away from the areas of greatest subsidence and towards the León and Pardomino ridges. The inferred angular unconformity due to the 4° tilting of the Leonides during the Upper Devonian can not be mapped in a single outcrop. The tilting occurred during the Bretonic phase of Stille (1924) and, since no folding was recorded in the present area, is regarded as an epeirogenic upheaval or tilting of specific blocks limited by the fundamental fault zones recorded.

b. Sudetic phase

The palaeogeographic features that most influenced the asymmetric folding and ultimate thrusting of the Leonides in the Bernesga-Porma area (fig. 63a) are,

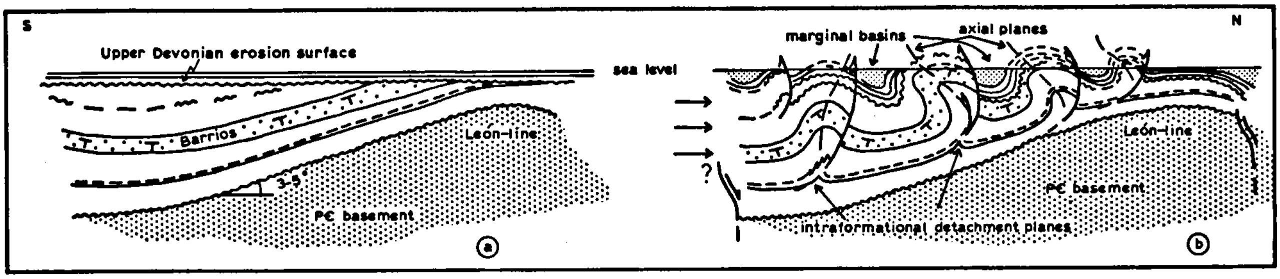

Fig. 63a. Diagrammatic section of the northern part of the Leonides illustrating 1. the thinning of the sedimentary series, 2. the outwedging of the most competent (Barrios) orthoquartzites and 3. the higher elevation of the basin margin (i.e. Léon line).

Fig. 63b. Illustrating the subsequent, asymmetric mode of thrust-folding due to the basin-outward directed force related to the Sudetic and Asturian folding phases.

the progressively higher elevation of the basin border north of the Sabero-Gordón and León hinge lines and the subsequent thinning and outwedging of the sedimentary series towards the León line.

The Bretonic uplift and subsequent erosion resulted in a decrease in thickness of the sedimentary series towards the León line of nearly 60 m per kilometer; this implies a relatively steep basinal slope of 3°—5° SSW (fig. 14). Since the radius of curvature of a fold is a direct consequence of the thickness of the sedimentary rocks involved in folding, the thinner flank facing the northern basin border will have a shorter radius and thus will be steeper than the opposite flank of that fold (de Sitter, 1956, p. 197). The basin-outward directed compressive force will thus give rise to asymmetric folds with steeply dipping axial planes. The original difference in elevation between the two flanks of the same concentric fold, due to the higher elevation of the northern basin border, might even result in (north dipping) axial planes which curve until facing the basin center (de Sitter, 1956, p. 239). Such a folding process explains the general geometry of the inverted Leonide upthrust units in the simplest and most logical way (fig. 63b).

The most competent, roughly 300 m thick, Barrios orthoquartzites clearly controled the width of the folds, but near the León line this formation also wedges out as a result of the Upper Devonian erosion. Due to the thinner section of sedimentary rocks involved in folding, the pressure is released by thrusting along lubricating beds below the competent Barrios Formation, but at a lower intraformational level (de Sitter, 1956, p. 240). This will result in detached anticlines in the upper part of the asymmetric fold and in axial planes that hade away from the steep flank. In the western extension of the Gayo Unit, the slip along the thrust fault decreases rapidly in a lateral way and splits up into faults which cross the sharp anticline diagonally.

The thick and competent orthoquartzites of the Barrios Formation are difficult to deform in concentric folds; the extensive diaclase and mylonite zones in this formation also indicate that it breaks rather than deform in an elastico-viscous way. Once the Barrios orthoquarrtzites in the steep northern flank of the asymmetric anticline have been broken, continued compression can result in upthrusts.

The detachment planes are usually located at the base of the Lancara Formation, suggesting that the black shales at the top of the Herreria Formation have acted as "lubricant". Large scale overthrusting appears to be possible under relatively small lateral stresses because the frictional resistance is reduced by the extremely high pressures of the interstitial fluids in the porous Herreria Formation if sealed off by rocks of low permeability (e.g. the black shales) and overlain by a thick overburden (ca. 2 km) (Hubert and Rubey, 1959).

This mechanism explains the general location of the thrust planes at the base of the Lancara Formation and the smooth fault-contact with the underlying strata. The dependence on the amount of overburden might also explain the abnormal thrust plane at the base of the Herreria Formation in the Bodón Unit. In this unit, the Upper Devonian erosion had decreased the thickness of the Lower Palaeozoic strata and therefore also the confining pressure necessary to realize the high fluid pressure that facilitates thrusting. As exposed east of Millaró, the thrust fault cuts deeper into the Herreria Formation, while the critical overburden pressure remains roughly constant due to the enlarged hiatus. The mean thickness of the Bodón Unit east of the Curueño River is about 2300 m. The superposition of the most competent and thickest formations (i.e. Barrios and Caliza de Montaña Formations) clearly influenced the wavelength and amplitude of the broad structures. Because the Devonian shales are absent, the Lower Carboniferous black shales and griottes will act as "lubricating" strata and generate the internal friction between these competent formations by means of strike slipping.

Because the smallest principal stress during the superficial thrust-folding against the inclined basin border lies in the vertical plane, the expansion will be predominantly in a vertical direction, while shortening prevails in the horizontal S-N direction (fig. 63). The initial folding was sub-marine, but since all stratigraphic data of the pre- and syntectonic sedimentary series indicate shallow marine depositional conditions, the culminations of the thrust folds will soon have emerged above sea level. Subsequent erosion produced the coarse detritic material of the greywackes in the foredeeps which are marginal to the thrust folds (fig. 63b and Schwan, 1949—1964).

The proportional erosion kept the vertical component of the stress field (gravitational pull) low enough so that a relatively small lateral force could maintain the vertical expansion until even the basal Lancara Formation of the thrust unit came into contact with the flysch deposits in front. On the other hand, the rapid accumulation of turbidites exerted a larger confining pressure and thus stimulated further subsidence of the southern flanks of the asymmetric marginal basins (e.g. the Carmenes syncline and Piedrafita Basin) along reactivated faults such as the Valdeteja and Valdehuesa fault zones.

The gradual filling of the marginal flysch basins is marked by the transition in depositional environment from shallow marine to paralic and even continental. The principle relation between the basins and ridges is shown by the fact that deposition kept pace with the large amount of subsidence.

A regional migration in time and space of the north-directed thrust-folding can be deduced from the early occurence of flysch tectofacies overlying the Visean griottes in the southern Alba Basin, while thick carbonate banks of Namurian age were still deposited further north (fig. 31). Fusulinid assemblages from the few limestone beds in the flysch deposits revealed a thick (< 1000 m) San Emiliano Formation of Bashkirian age as the youngest rock unit involved in the Leonides, while a condensed succession is recorded in the Asturides (app. V). Continued thrusting and contemporaneous refolding and back-folding during the Asturian phase resulted in a relative high in the Leonides, while reversed faulting along the León line gave rise to a very thick (> 2000 m) flysch deposition in the still subsiding Piedrafita Basin. The youngest fossil assemblages in this basin indicate the Upper Moscovian. Continued thrustfolding caused the repeated remodeling and narrowing of the marginal basin; this disturbed the equilibrium of the unconsolidated material and resulted in slumping and gliding in front of the approaching thrust units (fig. 32).

c. *Asturian phase*

Because the Forcada thrust fault cuts off Bashkirian to Upper Moscovian flysch deposits of the Lena Formation and is locally overlain by Stephanian molasse, it is concluded that the most important orogenic forces worked during the Upper Wesphalian Asturian phase. The intricately folded Peña Corada and Alba synclines represent the deepest part of the basin south of the Sabero-Gordón hinge line; from here, the thrust movement was generated towards the northern forelands. The dip of the strata in the northern flank of these synclines is usually steep, but becomes vertical and progressively more overturned towards the south.

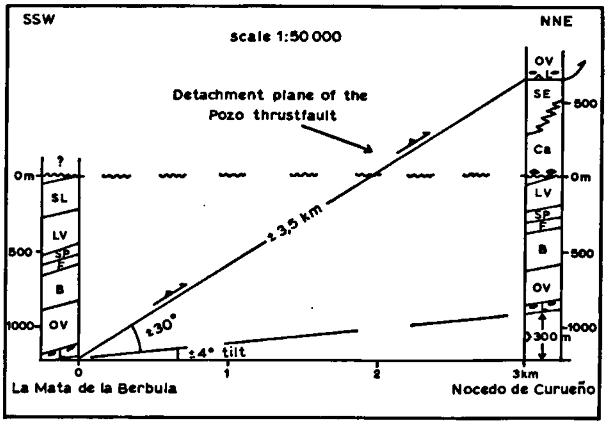

Fig. 64. Diagrammatic reconstruction of the Pozo "root zone", illustrating the steep angle (> 30°) of upthrust and the relatively small amount of overthrusting. The 4° tilt is mainly due to the Bretonic uplift.

The diagrammatic reconstruction of the root zone of the Pozo Unit between Nocedo de Curueño and La Mata de la Berbula (fig. 64) illustrates the steep initial dip (> 30°) and relatively small amount of overthrusting which is also considered representative for the other thrust units. As could be deduced from the columnar sections and the geological map, the approximately 1800 m thick succession in the back of the Gayo Unit is cut off within 3.5 km by the Pozo thrust fault, which dips more than 30° SSW and is therefore called an up-thrust.

The amount of displacement along the upthrust and the dip of the thrust plane are roughly proportional to the thickness of sedimentary series involved; in the case of an initial dip of 30°, the length of the thrust fault will be twice the mean thickness of the strata involved. Only a relatively small amount of (low angle) overthrusting occurs in most of the frontal parts of these thrust units, because the detached basal layer is usually brought in contact with the contemporaneously deposited flysch facies in the marginal troughs.

A relatively small amount of overthrusting is also concluded from the appearance of the more or less complete southern flanks of the thrust units. This is quite obvious for the western extensions of the Pozo Unit, but more difficult to indicate elsewhere. The exposures of Alba griottes and older strata in the southern flanks of synclines SW of Carmenes, Valdeteja, Canseco, Redilluera and Lodares suggested a small amount of thrusting and provided the information needed for the construction of the tectonic cross-sections.

Figure 65 illustrates the different (interpretation of the) thrust-folding on either side of the Pardomino Ridge. In the present area, the theoretically derived amount of thrust-movement does not exceed twice the mean thickness of the strata involved (2—6 km). The extensive Esla Unit east of the Pardomino Ridge is more than 15 km long (Rupke 1965, p. 58), while Sjerp (1967, p. 117) computed 4—10 km for the

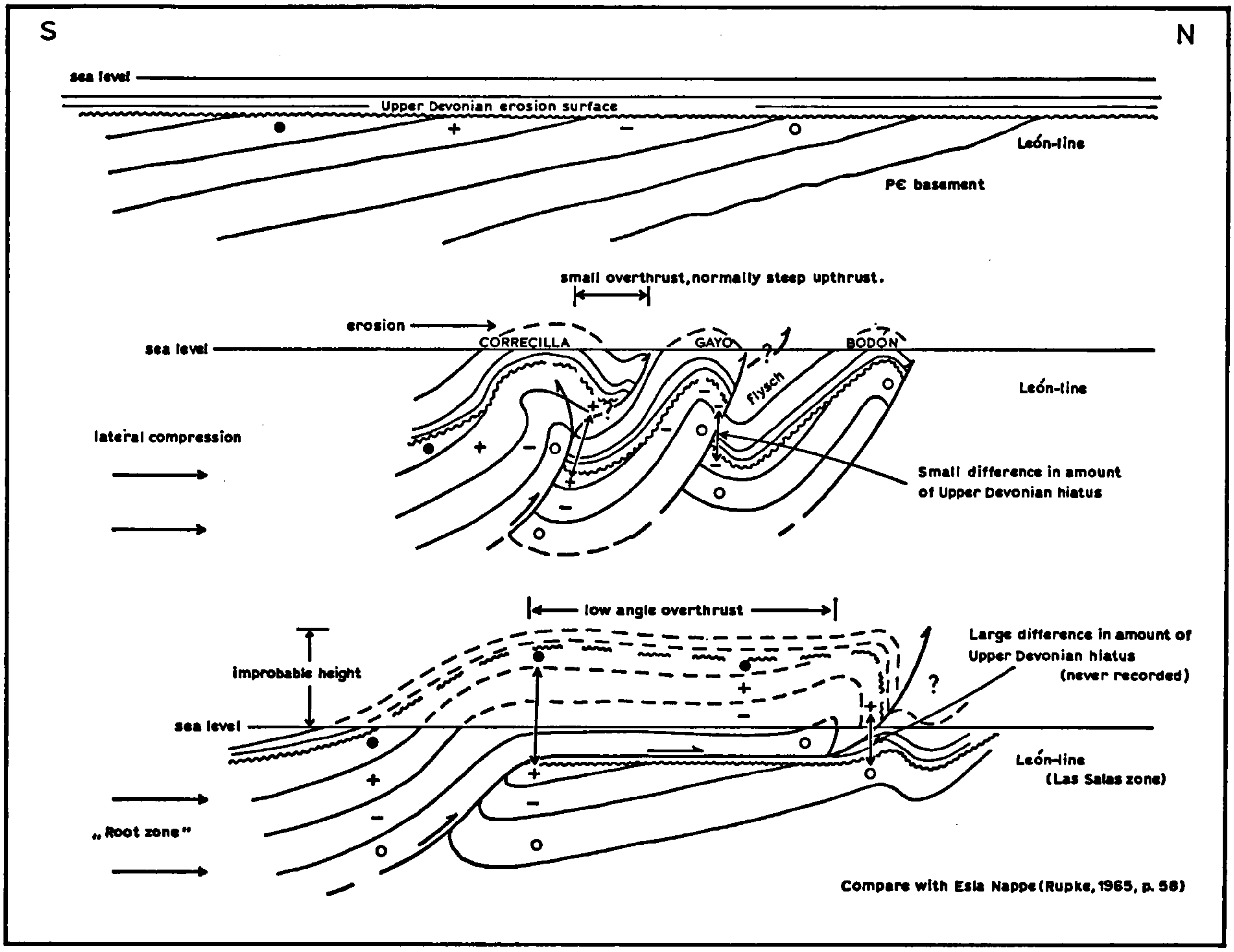

Fig. 65. Illustrating the steep upthrust with a relatively small amount of overthrusting in the present area, in comparison to the low angle overthrusts deduced by Rupke (1965) for the Esla Nappe.

refolded overthrusts in the area to the north. The poorly exposed Bregón Unit does not feature any flysch deposits in front of the thrust fault, but is thrusted on the Huergas Formation and otherwise appears to be comparable to the Esla Unit as exposed east of Boñar. Rupke (1965, p. 57) interpreted this unit as a low-angle overthrust with considerable displacement.

Another deviating picture was mapped in the front of the rapidly upcutting Correcilla thrust fault in the Sancena Mountains, north of Rodillazo. Near the villages of Gete and Valdorria, the Lancara Formation is cut off and the thrust fault bends north towards the topographically higher (ca. 600 m) Sancena Mountains. Here the Santa Lucia Formation in the front of the Correcilla Unit is in contact with the Caliza de Montaña Formation of the Gayo Unit. A relatively small thrusting over a thinning San Emiliano Formation must be concluded (sections 4 and 5). A comparable overriding of flysch deposits is assumed for the Gayo Unit SE of Valdeteja, the Bodón Unit SE of Arintero and for the Forcada Unit in the Ferreras area.

The strike of the basin-outward directed thrust folds and the position of the fore- and back-troughs are clearly controlled by the WNW-ESE trending León and Sabero-Gordón lines and the WSW-ENE trending Pardomino Ridge (fig. 66). It is not possible, nor is it necessary from the mechanical point of view, to separate both folding trends chronologically. Local stress conditions varied in response to the palaeogeography of the basins and ridges, while a roughly S-N stress field continued to compress the sedimentary series.

Most probably the broad Montuerto, Valdehuesa and La Venta structures originated contemporaneously with the thrust-folding, because the thrust sheets were pushed into the wedge between the fundamental León and Pardomino ridges. The interference of the NNE-directed thrusting with these ridges thus produced a Z-shaped thrust plane parallel to the originally curved axial plane. This shape caused an obstruction to further

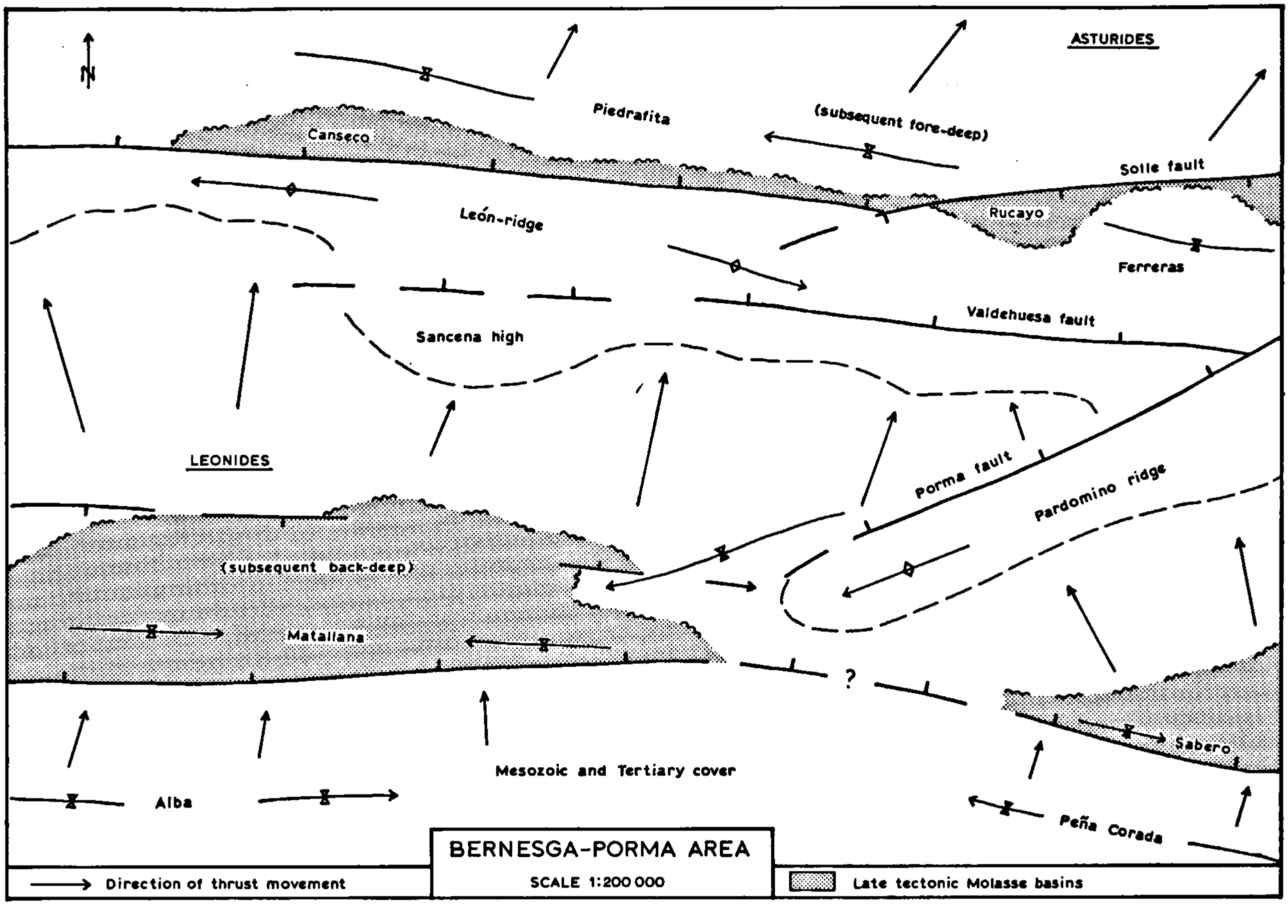

Fig. 66. Illustrating: 1. the fundamental fault zones and ridges, 2. the direction of thrust-movement and 3. the subsequent fore-deep marginal to the upthrusts, and the molasse basins in the back of the upthrusts.

movement along the thrust planes so that continued compression resulted in the refolding of the thrust sheets. It is also possible that these steep folds were further accentuated due to the stress field generated by the NNW directed thrust-folding of the Pardomino anticlinorium, or due to continued normal and wrench fauting along the Porma, Valdehuesa and Solle faults (fig. 67).

The subvertical plunge of the Montuerto, La Venta and Valdehuesa fold axes and the silicified fault-breccias along the broken axial planes suggest that restricted, late-tectonic wrench faulting might have taken place, probably contemporaneously with the normal faulting. The right-lateral movement along the Valdehuesa Fault might also explain the steep cross-folding in the Forcada Unit east and north of Valdehuesa (fig. 57) and the synformal character of the core of the Valdehuesa anticline. Comparable synforms were recorded in the western terminations of the Pardomino and Gayo anticlines, where the related Porma and Valdeteja faults end in a splay of minor faults differing little from the main strike. The asymmetry of the steeply plunging "drag folds" along the Porma Fault also suggest a certain amount of horizontal displacement (fig. 68).

The set of wrench faults, generated by the same N-S stress field that caused the thrust-folding, is shown in figure 67. The remarkably close connection and transition between normal faulting, thrusting and wrench faulting is an indication of their combined mechanism. The probable basculating character (de Sitter, 1956, p. 167) of the Solle and Porma faults can only be studied in a larger region (de Sitter, 1956, p. 166—169 and 1966).

The changes in facies and thickness recorded in the Piedrafita Basin (app. V) influenced the dimension of the folds. The thick limestone beds at the base of the Lena Formation control the wavelength and amplitude of the disharmonic folding, while towards the top and in the southern part of the basin, the greywacke banks control the geometry of the folding. As a result of the thickening of the Lena Formation towards the west, the larger confining pressure gave rise to more bedding plane fissilities, slaty cleavage and distorted fossils in the more deeply buried areas around Piedrafita de Torío.

The relation between the "supra-structures" in the flysch deposits of the Piedrafita Basin and the large, refolded thrust faults in the Lower Palaeozoic "basement" was mapped by Sjerp (1967) in the San Isidro-

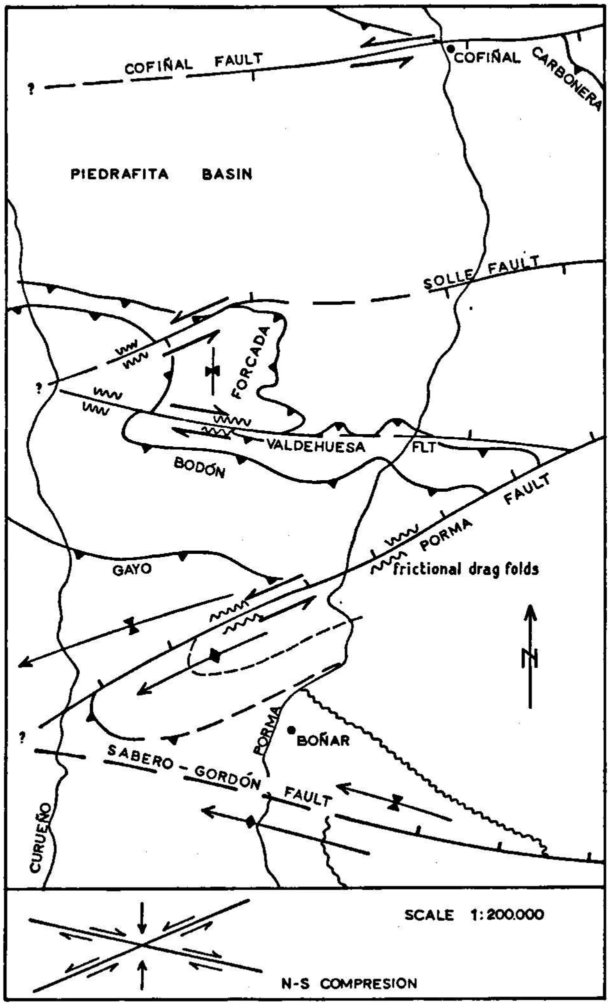

Fig. 67. Late-tectonic wrench fault movements along existing fault zones, probably due to a roughly N-S stress field.

Porma area just NE of the present area (location map, app. V). The broad, roughly E-W trending, incongruous refolding is dated between Westphalian D and Stephanian B. The north-dipping axial planes of the asymmetric major folds suggest a south-directed stress field, probably related to the second part of the Asturian phase (de Sitter, 1966, p. 119). The superficial push from the north might have affected the stacked Leonide thrust folds, which are further inverted by thrusting along the existing faults which already dipped more than 45° S (fig. 69). The south-directed stress field is, however, not necessary to explain the ultimately back-folded thrust units of the Leonides; because, as illustrated in figure 63, the asymmetric folding against the higher basin border (León line) could produce north-dipping axial planes with long and steeply overturned southern flanks facing the basin center. In the present area, it appeared impossible to specify the relation in time and space of the Asturian orogenic phase further than: a N-S compression during the Westphalian.

Fig. 68. Steep north-dipping frictional drag folds in the Oville Formation just north of the Porma Fault, SW of Valdecastillo.

Slaty cleavage has been found in the incompetent argillaceous beds between the concentrically folded limestone and greywecke banks of the Lena Formation. The oblique cleavage appears to flatten the asymmetric folds and might be due to an oblique shearing movement in relation to the thrusting in the deeper and more resistant rock units (fig. 70). At locations on the inverted southern flank of the asymmetric anticlines where the direction of aging could be established on palaeontological and sedimentological grounds, the tectonic analysis pointed to an opposite direction of shear movement, suggesting a basin-inward directed gravitional gliding as the most probable origin of the oblique shearing (fig. 71b). The boudinage structures and elongated fossils recorded in thin sections (fig. 60) also illustrate the stretching and subsequent thinning of the layers. Detailed tectonic analyses, as carried out by Savage (1967) in the Yuso Basin east of Riaño, are however necessary to determine the proper mechanism which deformed the Lena Formation in such a complicated way, and to decide whether the vertical movements along the León and Cofiñal fault zones did indeed result in a comparable tectonic setting.

d. Saalic phase

The Sudetic folding phase had stacked several thrust folds against the León and Pardomino ridges which were refolded by the Asturian paroxysmal phase and

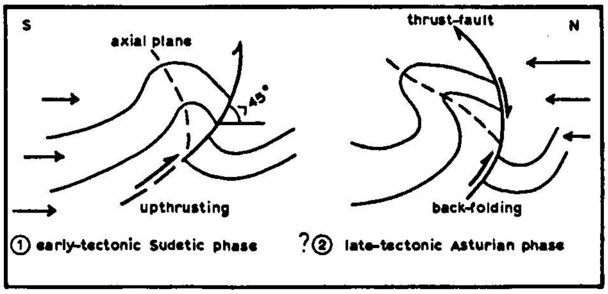

Fig. 69. Continued upthrusting and back-folding of the Leonides during the Hercynian folding phases.

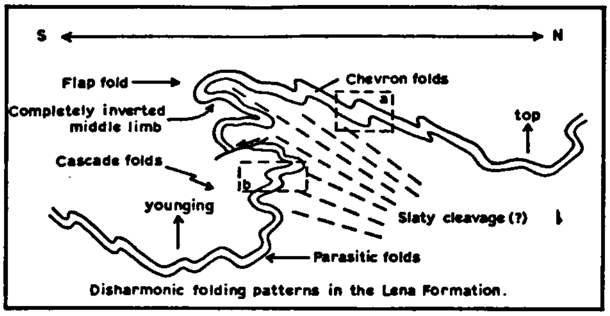

Fig. 70. Disharmonic folding patterns in the northern flank of the Piedrafita Basin. Detailed sections a. and b. are shown in fig. 71.

probably disturbed the isostacy. Late- and post-orogenic adjustments then resulted in subsequent oblong depressions in the "back" of the thrust fold zone, where the erosional products of the repeatedly uplifted northern culmination areas were rapidly deposited in tectonically restricted, intramountainous molasse basins (fig. 72). This morphogenetic process was pulsatory and long-lasting, since deposition during one cyclothem roughly kept pace with subsidence.

Tectonism was mainly restricted to normal faulting along fundamental weakness zones in the older Palaeozoic "supra-basement", and the thickest development of the asymmetric Matallana and Rucayo basins is therefore clearly tied to the fundamental faults of the Sabero-Gordón and León lines. The observation that some faults in the southern boundary of the Matallana and Rucayo basins are only partly covered by the Stephanian B deposits illustrates that the displacement along these syn-depositional faults was relatively small, but locally continued until after the Stephanian B (fig. 72).

The south-dipping thrust faults and the steep to inverted dip of the greywackes in front of the Sabero-Gordón line suggest secondary tangential forces, due to lateral shortening of the incompetent Stephanian cover after repeated downthrow of the northern basement along reversed faults. Such upthrusts are difficult to map since continuous markers are lacking, but Helmig (1965, p. 135) did succeed in tracing such thrust faults in the Sabero Mines.

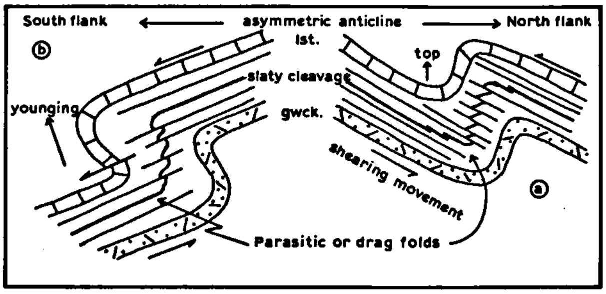

Fig. 71. Slaty cleavage and parasitic folding in chevron folds (a) and cascade folds (b) in the Lena Formation.

The long and barely deformed northern flank of the Matallana Basin has a monoclinal aspect. The initial syn-depositional deformations of the molasse sediments are shown by the angular unconformities between the basal conglomerate beds, but most deformations in the northern flank are due to differential compaction over the pronounced, intramountainous palaeorelief. The thrust faults along the Sabero-Gordón line were locally reactivated during the late-tectonic Saalic phase (e.g. Casetas Fault east of San Adrian). Tertiary (Savian) faulting along the Sabero-Gordón line further disturbed the section (La Llama Fault east of Las Bodas).

Figure 72 illustrates the schematized evolution of the Matallana and Rucayo synclines during the Stephanian. The rapidly outwedging conglomerates in the northern flank of the molasse basins suggest that part of the fault movement was synsedimentary.

Wagner's hypothesis (1966, p. 80—86) that the Sabero and Rucayo Formations were equally deposited over an extensive, tectonically unrestricted region and that only post-depositional, compressive tectonism followed by a long period of erosion might exclusively have created the present distribution of the molasse must be rejected in view of the sedimentological and structural data.

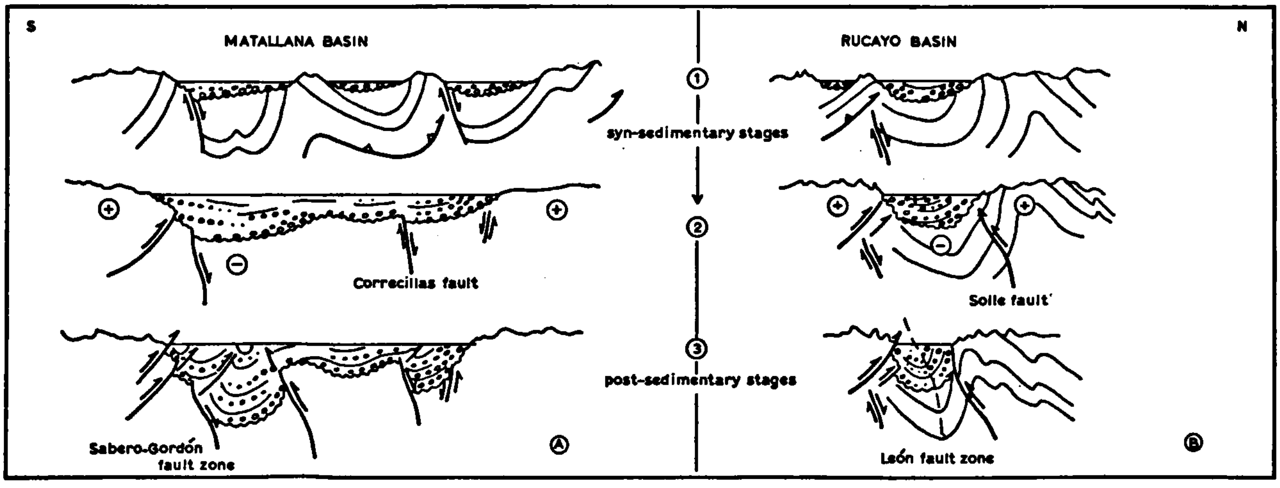

Fig. 72. Diagrammatic picture of the evolution of the Matallana and Rucayo basins.

2. Alpine Period

e. Savian phase

The large gap in the stratigraphic record between the Stephanian and Upper Cretaceous makes it difficult to indicate how the Palaeozoic rocks were deformed during that period. The unconformable contact of the Voznuevo Formation on the Sabero Formation, as exposed about 5 km east of Las Bodas, illustrates that the Stephanian strata had been deformed and tilted more than 40° S, before the Upper Cretaceous was deposited on top of it. A reconstruction of the pre-Cretaceous geometry of the Alba and Peña Corada synclines, as exposed near Matallana-Estación and San Adrian (fig. 73), illustrates the possible relation between the amount of dip of the Cretaceous strata and the variations in dip due to the Alpine flexuring. Where the Cretaceous dips only 35°S (San Adrian section), the flysch facies dip 45°—65° S; in the Matallana-Estación section (3) however, the Cretaceous is folded subvertically and the Carboniferous is consequently in an overturned position. Further east, the Cretaceous covers part of the Corada Unit and dips progressively more steeply towards the south until the influence of the Cistierna fold-thrust is again reflected in the subvertical position of the Cretaceous and overturned dip measurements in the Carboniferous.

The E-W trending uplift of the Hercynian Mountain Range started in the Paleogene and climaxed with the deposition of large piedmont alluvial fans consisting of very coarse limestone and quartz conglomerates. Since the Candanedo Formation is also folded in a steep flexure and unconformably overlain by subhorizontal "red-beds" of Miocene age, the morphogenetic uplift might be correlated with the Savian phase of Stille. The growth of the uplift was gradual, as can be inferred from the scarcity of angular intraformational unconformities and the occurrence of increasingly older rock fragments from the rising mountain flank — "inversed sedimentation" (fig. 74).

The doming movement of the Cantabrian Mountains was concentrated along an E-W trending flexure zone of limited width and probably rooted by deepseated vertical faults. The arcuate form of the Valdepiélago and other mountain-flanking faults (Evers, in prep.), indicates that the segment of maximal uplift turned towards, and partly overthrusted, the adjacent downwarped marginal basins, which received large quanties of locally derived rock debris. The vertical uplift was also accompanied by the growth of overturned asymmetric folds, which culminated in thrusting due to local inclined stress fields away from the uplifted area.

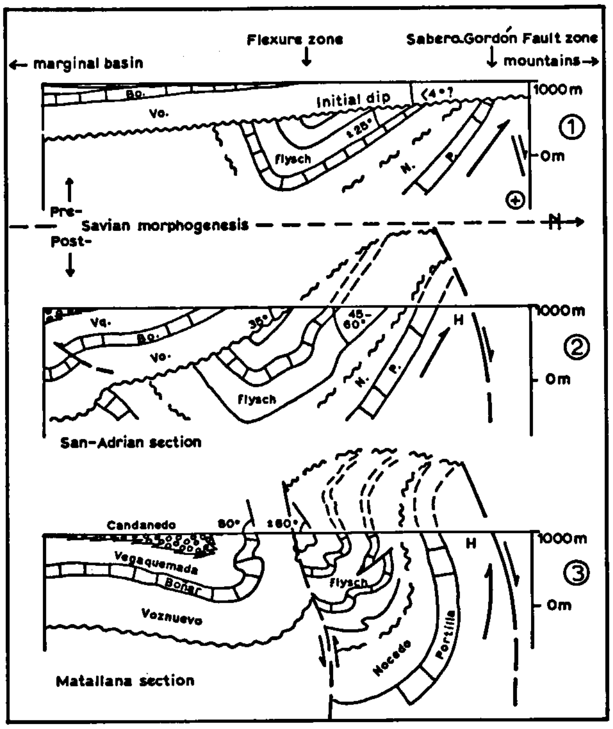

Fig. 73. Influence of the mountain flexuring (Savian phase) on the dips in the northern flank of the Corada (2) and Alba synclinoria (3).

The genetic relationship between these mountain flank structures and their adjacent basins is best described by the term "fold-thrust uplift" (Berg, 1962).

The Valdepiélago Fault is over 10 km long and the maximal overlap measured east of Ranedo is less than 1 km. The gravity profile in the Curueño Valley (fig. 76) gave adequate subsurface information for the interpretation of a steep north-dipping Valdepiélago Fault with a throw of over 1 km. Since the dip of the S-shaped fault plane is variable, the gravity data helped to determine whether the steep root zone, the flatter middle limb or the steep frontal part of the S-shaped fold-thrust is exposed (fig. 74 top).

The La Llama Fault, belonging to the Sabero-Gordón line, was also reactivated and displaced the Voznuevo, Boñar and Vegaquemada Formations by reversed faulting (cross-section 7).

The Savian morphogenetic phase is the last important deformation; later isostatic adjustments caused only minor tilting, which is reflected in elevated erosion and peneplanation surfaces recorded outside the mapped area.

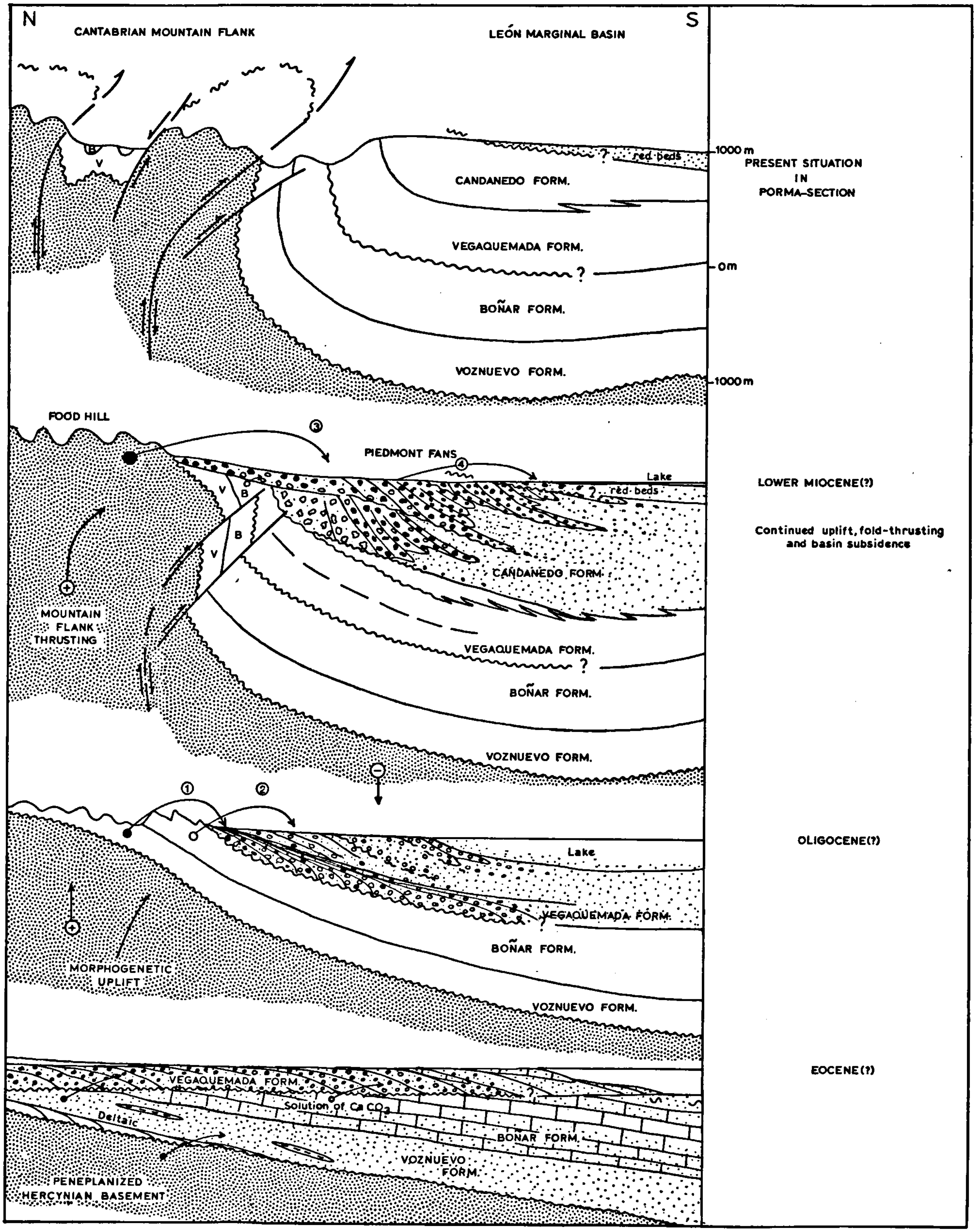

Fig. 74. A schematic reconstruction of the mountain flexure zone and associated fold-thrusting during the Paleogene (Savian phase). Note the inverse sedimentation patterns.

BOUGUER GRAVITY CONTOURS

The Bouguer Anomaly map (fig. 75), covering roughly the same area between the Bernesga and Porma rivers as described in the present paper, is derived from an extensive gravity survey carried out by the Leiden department of Geophysics and Hydrogeology under supervision of Prof. Dr. J. G. Hagedoorn. This investigation was primarily aimed at the so-called Southern Border Fault Zone of the Cantabrian Mountains, where large scale mountain flank thrusting was expected. It was further extended to include the León line and the NW part of the Tertiary Duero Basin, (Evers, in prep).

The straight lines on the map represent those sections of the gravity profiles in the roughly N-S running Torío, Curueño and Porma rivers, which correspond with the sections of figure 76. The densities of the rock units exposed, were kindly determined at the Kon./Shell Exploratie en Productie Laboratorium at Rijswijk and were composed to a mean density of 2.67 g/cm^3 for the Palaeozoic and of 2.46 g/cm^3 for the Upper Cretaceous and Paleogene rocks. The considerable density contrast (ca. 0.21 g/cm^3) between the rocks on both sides of the mountain flexure zone could produce large effects in the Bouguer Anomily profiles (e.g. 12 mgal in 3—4 km).

The profiles run roughly perpendicular to the geological strike and consequently, to the Bouguer gravity contours. They are schematically interpretated as illustrated below the abscissa of each section. In the Porma Valley, the profile north of Boñar runs over the unconformable contact of the Upper Cretaceous Voznuevo Formation with Palaeozoic rock units; the angle of approximately 30° agrees well with field measurements (see geological map). The Valdepiélago Fault is here located between Palaeozoic rocks and, consequently, is not represented as a Bouguer anomaly. The Pardomino anticline and Montuerto syncline are probably noted because the fundamental Porma Fault also displaced the Precambrian basement which consists of denser, metamorphosized slates ($d = 2.70\,g/cm^3$). The relatively small effects south of Valdecastillo are due to local density variations in the Palaeozoic rocks. The western extension of the San Adrian anticline is noted north of Palazuelo de Boñar, while south of this village, the western extension of the Cistierna Fault appears.

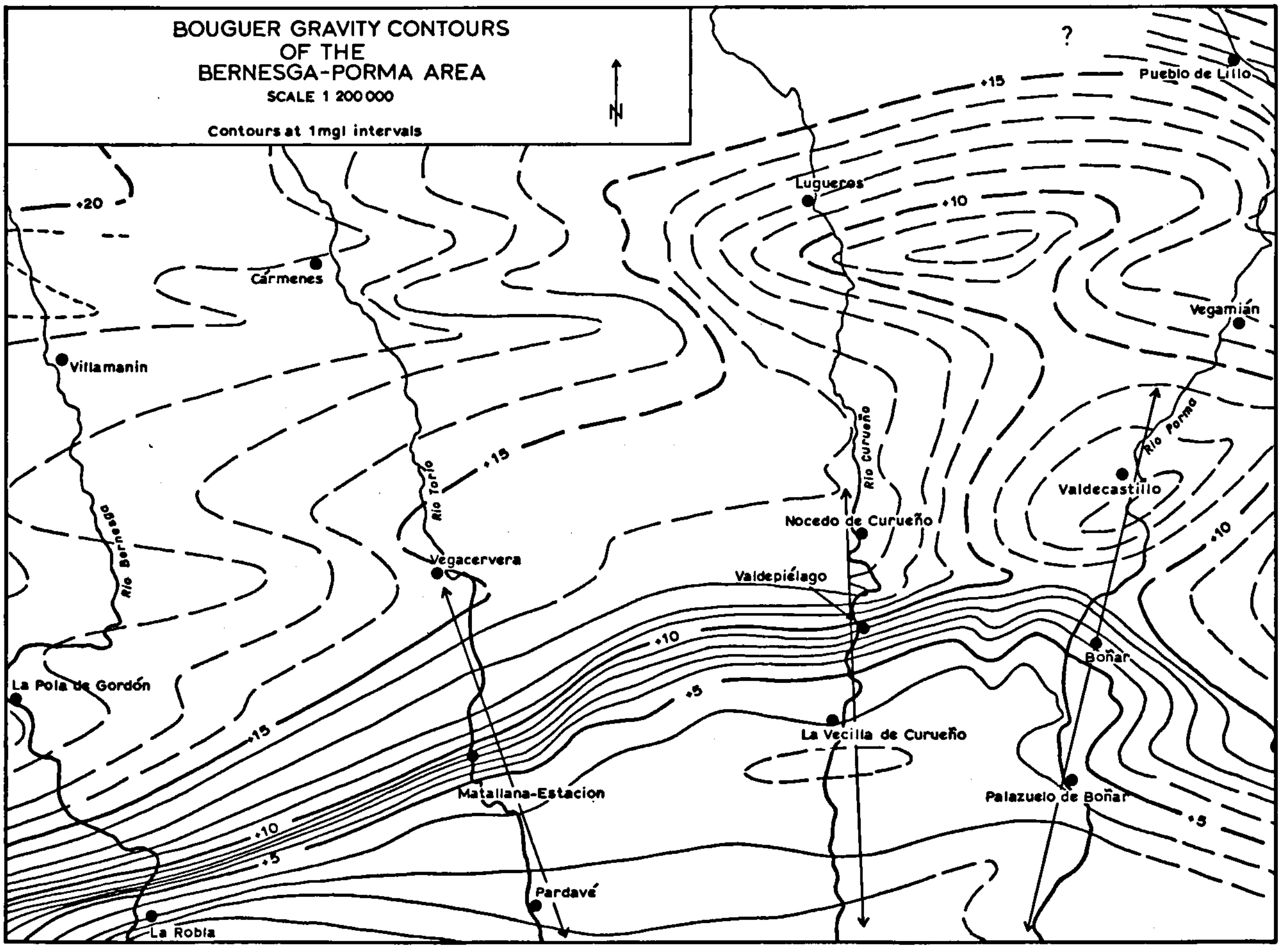

Fig. 75. Bouguer Anomaly map of the Bernesga-Porma area. Note the steep gradient in the gravity contours coinciding with the mountain flexure zone.

In the Curueño section, the displacement along this fault is further reduced to 150 m; the Valdepiélago Fault here forms the southern border of the Palaeozoic core of the Cantabrian Mountains; the displacement along the sub-vertical fault is well over 1 km. In the Torío section, the thrust fault appears to incline towards the down-warped Tertiary León Basin and away from the uplifted Leonides.

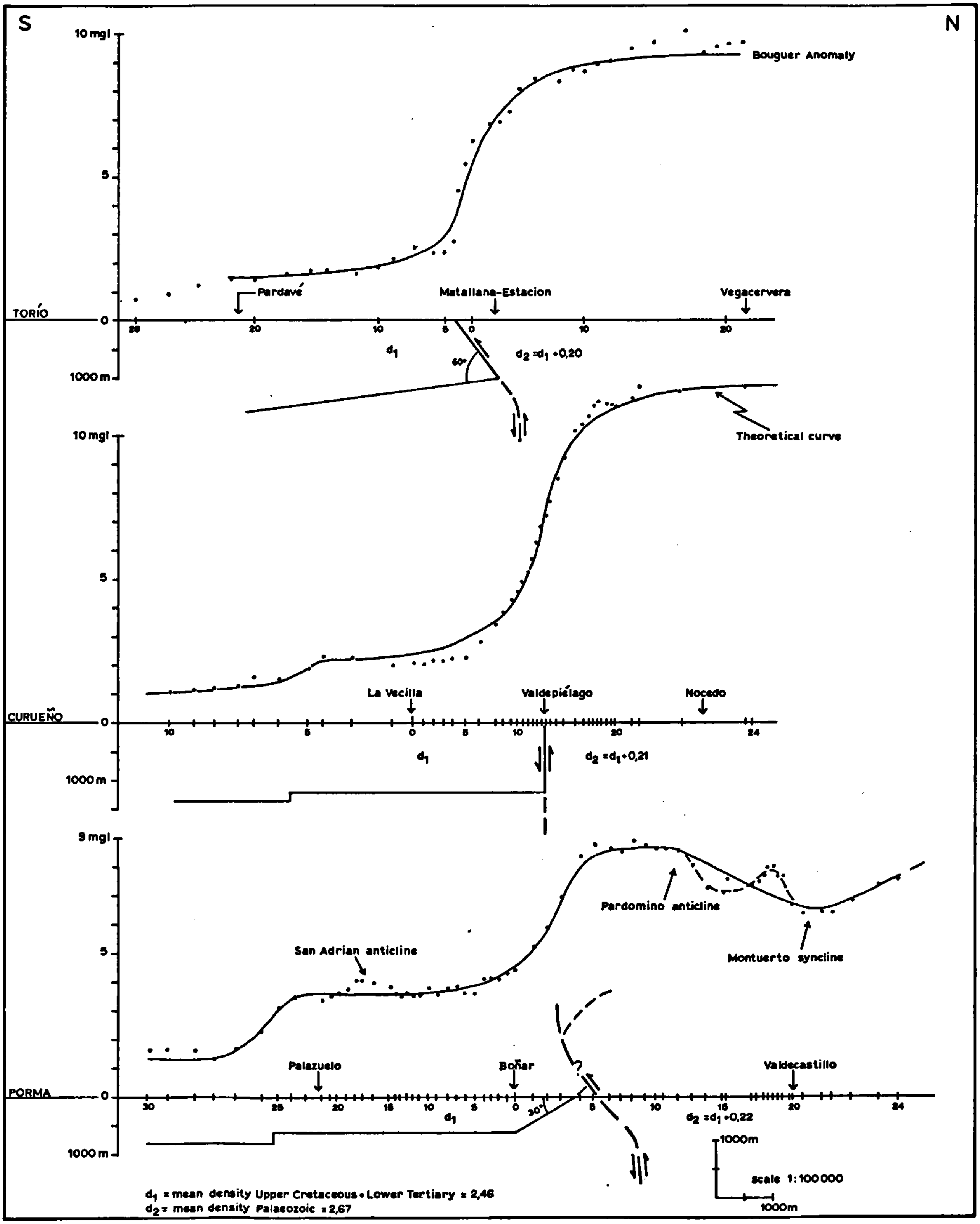

Fig. 76. Gravity profiles through the Torío, Curueño and Porma valleys and their interpretation.

GEOLOGICAL HISTORY

The relations in time and space of the Hercynian tectogenetic and Alpine morphogenetic periods marked by (basal) conglomerates and tectofacies is visualised in figure 77.

This schematic representation of the tectono-stratigraphic evolution of the Bernesga-Porma area clearly illustrates:

1. The relation of the fundamental León line to the Bernesga, Piedrafita and Rucayo basins, and of the Sabero- Gordón hinge line to the Alba and Matallana basins.
2. The *stratigraphic* control of the initial asymmetric folding and thrusting of the Leonides (Sudetic phase) and the subsequent *tectonic* control of the asymmetric marginal basins separated by emerging upthrust units and filled with flysch.
3. The intermittent, gradually climaxing tectonism of the Asturian folding phase resulted in the ultimate elimination of the marginal basins and the refolding of the Leonides, while the major Piedrafita Basin was still subsiding. A different type of deformation is therefore recorded in the supra-structures of the Lena Formation (parasitic folding and cleavage).
4. The start of the long period (Stephanian-Upper Cretaceous) of post-orogenic structural adjustments is reflected in the deposition of molasse in intramountainous coal basins, which are primarily related to reversed faulting along the fundamental Sabero-Gordón and León fault zones.
5. After a large gap in the stratigraphic record, the Upper Cretaceous transgression over a peneplanized Palaeozoic basement introduces a different evolution during the Tertiary.
6. The southern border of the Cantabrian Mountains is marked by extensive fold-thrusting during the Savian morphogenetic uplift of the Palaeozoic core and the subsequent down-warping of the León marginal basin, which is rapidly filled by torrential piedmont deposits.

I wish to emphasize that the geomechanic representation of the Hercynian and Alpine mobile phases, as reflected by the stratigraphic successions in the present area, indicates long-term tectonic activities in contrast to the much propagandised concept of relatively short-term thrust movements.
The direction of migration for these thrusts is essentially perpendicular to the general tectonic trends in the basement (fig. 66). In the case of the compressive Hercynian phases, the displacement of the strata was directed *away* from the central axis of subsidence (i.e. Alba syncline). The vertical displacement due to the Alpine morphogenetic uplift was diverted by potential (gravity) forces *towards* the subsiding León Basin.

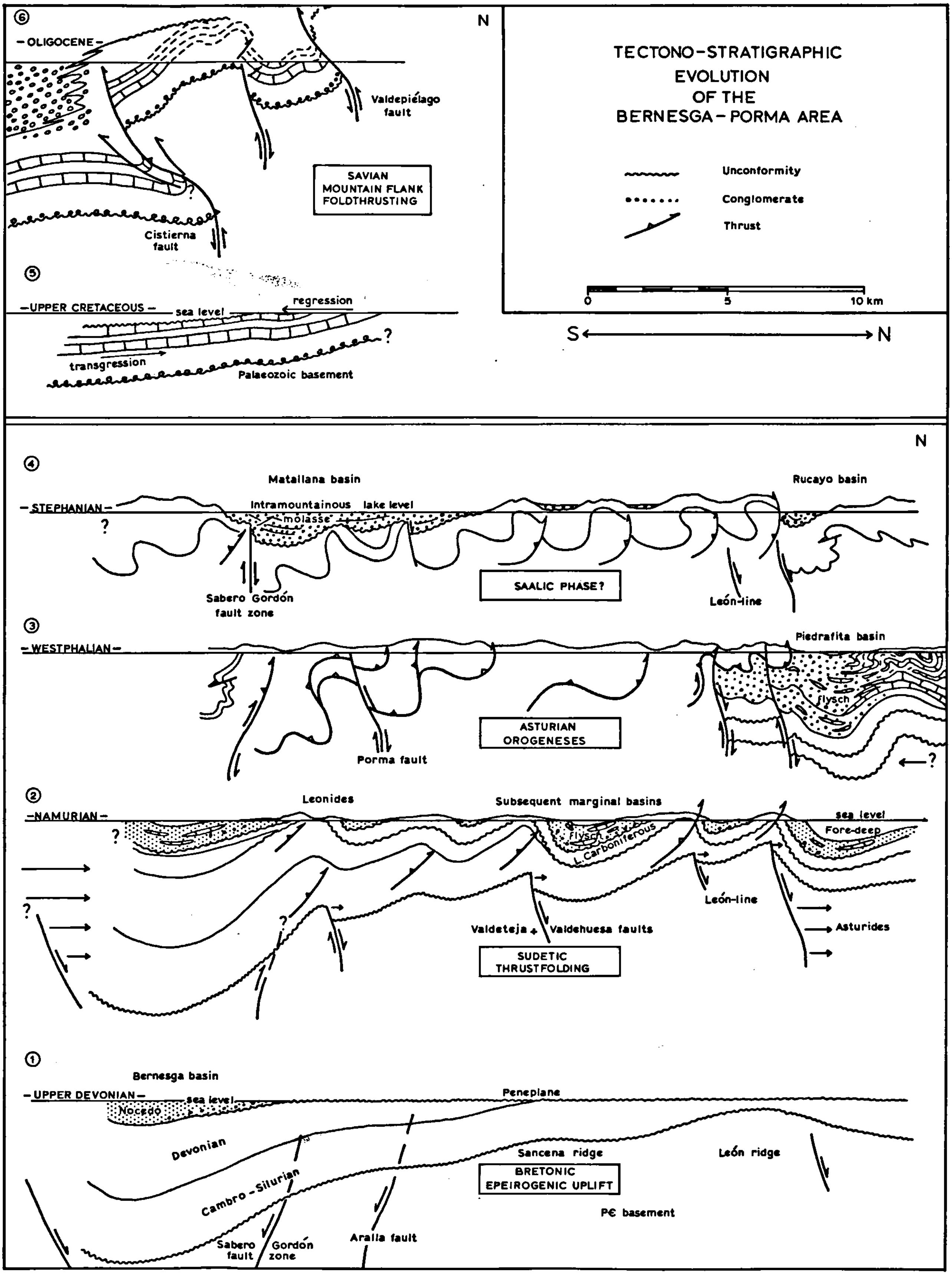

Fig. 77. Diagrammatic representation of the tectono-stratigraphic evolution of the Bernesga-Porma area.

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