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THE DISTRIBUTION AND DEVELOPMENT OF POST-LEONIAN STRATA (UPPER WESTPHALIAN D, CANTABRIAN, STEPHANIAN A) IN NORTHERN PALENCIA, SPAIN

R. H. WAGNER* & W. J. VARKER**

ABSTRACT

Detailed stratigraphic investigations, based on the recording of sections to the scale of 1 : 100, have provided an insight into the distribution and development of a succession of upper Westphalian D and lower Stephanian (*sensu lato*) strata in northern Palencia, Cordillera Cantábrica. A maximum development of *ca.* 5000 m is recorded. Everywhere in northern Palencia the succession begins at a disconformable contact with Upper Moscovian rocks which have been almost invariably eroded to a level just above or within the Sierra Corisa Limestone Formation. The corresponding uplift, quickly followed by local downwarp and normal faulting, is referable to the Leonian Phase which produced folding in nearby north-eastern León. The post-Leonian deposits in northern Palencia were formed at first only in the north-western part of the area considered (text-figs 1, 10) where upper Westphalian D strata were laid down in basin sags which gradually expanded their area by progressive onlap. Eastwards, the basin was temporarily limited by a normal fault zone with syn-sedimentary movement (Los Llazos Fault). This fault, between Peña Tremaya and Los Llazos (text-figs 1, 10, 13), ceased to function at the Rosa María coal horizon, 2100 m above the base of the first deposits in the post-Leonian basin, and this allowed the basin to extend further eastwards, onto the block. Tentative correlations with sections not yet investigated in detail but recorded in the literature from Barruelo and the Redondo Syncline (text-fig. 11), and also with sections studied most recently by the present writers but not illustrated in text-fig. 11, indicate that sedimentation in those areas commenced at or above the Rosa María horizon after the extension of the basin over the Los Llazos Fault Zone (text-fig. 13).

Sedimentation ranged from shallow, rhythmic, marine basin deposits, through shallow agitated marine basin sediments with regressive rhythmic units leading upwards occasionally into root beds and coals, to turbidite deposits and back into shallow marine basin deposits with intervals of coal-bearing strata. The latter become gradually more important in the highest part of the succession, as represented in the Barruelo area. The intermittent downwarp along the Los Llazos Fault may have exerted control on the rhythmic sedimentation.

The overall correlation of sections is represented in text-fig. 11, and examples of sequences measured are given in text-figs 2-9, 12. Alternating horizons with fossil land plants, brachiopods and fusulinids provide the elements of stratigraphic dating. Floras of upper Westphalian D age occur up to the level of the Casavegas coals, the base of the lower Stephanian (*sensu lato*) being found perhaps a little below the Areños coals. A clear-cut Stephanian A flora appears with the Carboneros in the Barruelo section, and the lower Stephanian (*s. l.*) below Stephanian A is assigned to the Cantabrian Stage introduced by WAGNER (1966). Faunas indicate Myachkovian and Kasimovian ages for the post-Leonian succession investigated. More detailed work on the floras and faunas is in progress.

* Geology Department, The University, St. George's Square, Sheffield S1 3JD, England, U. K.
** Department of Earth Sciences, The University, Leeds 2, England, U. K.

RESUMEN

Una investigación detallada, basada en cortes medidos a escala 1 : 100, ha empezado a elucidar el desarrollo estratigráfico y la distribución de sedimentos del Westfaliense D superior y del Estefaniense inferior (*sensu lato*) en una sucesión post-tectónica de más de 5.000 metros espesor en el norte de la provincia de Palencia, Cordillera Cantábrica. Esta sucesión comienza siempre por un contacto erosivo con estratos del Moscoviense superior al nivel de la caliza de Sierra Corisa (ó caliza de Peña Maldrigo, etc...). Los movimientos tectónicos correspondientes, que se manifiestan en Palencia por una disconformidad debida a levantamiento seguido por un hundimiento de cuenca limitada por una zona de fallas directas (Falla de Los Llazos - Figs 1, 10, 13), están descritos del nordeste de León como un plegamiento importante (Fase leonense).

La sedimentación post-leonense en el norte de Palencia se inició en la zona de Casavegas (Fig. 1), instalándose la cuenca al principio en hondonadas formadas por flexuraciones locales del subsuelo; flexuraciones que se hacen cartografiar muy bien por la forma de la caliza de Peña Maldrigo al W de Casavegas y al NW de Lores (Fig. 1). La zona de hundimiento se extendió paulatinamente hacia el este y sureste, hasta que llegó a la Falla de Los Llazos que formaba el límite con un macizo estable. Aquél debe probablemente identificarse con el Bloque Cantábrico, cuya extensión era menor que en tiempos anteriores. La Falla de Los Llazos actuó como límite de sedimentación durante el tiempo correspondiente a la formación de los primeros 2.100 metros de estratos, y cesó al nivel de las capas de Rosa María (Fig. 13). Desde aquél momento la cuenca de sedimentación se extendió gradualmente hacia el este, transgrediendo el macizo.

Una correlación provisional con los cortes aún poco estudiados en la zona de Barruelo y en el valle de Redondo (Fig. 11) indica que la sedimentación en aquellas zonas se inició como más pronto al nivel de Rosa María.

El tipo de sedimentación varía de cuenca marina somera con ritmos transgresivos a cuenca marina de ambientes aún más someros y caracterizados, sobre todo, por ritmos regresivos que se basan en transgresiones súbitas, cuyo origen buscamos en los movimientos repetidos de hundimiento por la falla directa de Los Llazos. Los ritmos regresivos llegaron a menudo a rellenar la cuenca marina, ya que en varios casos notamos la presencia de suelos de vegetación e incluso capas de carbón al final del ritmo. Este tipo de sedimentación rítmica caracteriza a la Formación Ojosa. Después, con la Formación Brañosera debió de cambiar la configuración paleogeográfica y formáronse turbiditas. Al final de esta formación y en la Formación Barruelo se formaron otra vez ritmos regresivos, con capas de carbón en varios intervalos que, paulatinamente, venían a ser más ampliamente continentales. En total, un máximo aproximado de 5.000 metros de estratos fueron depositados en la cuenca post-leonense de Palencia que contiene la sucesión más completa del Westfaliense D superior, Cantabriense y Estefaniense A (representando estos últimos el Estefaniense inferior *sensu lato*) en España y en Europa Occidental.

La Figura 11 da la correlación general entre las sucesiones presentes en el Sinclinal de Casavegas, el Sinclinal de Redondo, y en la zona de Barruelo. Las Figuras 2 a 9, y 12 se presentan como ejemplo de los cortes estratigráficos medidos con detalle.

La presencia de faunas marinas en estratos alternando con los que dan flora continental ha permitido establecer ciertas correlaciones de índole cronoestratigráfico. En el tramo hullero de Casavegas se han encontrado floras del Westfaliense D superior, y a partir del tramo de Areños empiezan las floras del Estefaniense inferior *sensu lato* que claramente se manifiestan en los tramos hulleros de Verdeña y San Cristóbal. Las floras del Estefaniense A (Estefaniense inferior *sensu stricto*) se encuentran solamente en los tramos de los Carboneros y del Calero de la Formación Barruelo (Wagner & Winkler Prins 1970). Por lo tanto, una gran parte de la sucesión post-leonense del norte de Palencia pertenece al Cantabriense. Las faunas marinas (fusulínidas — estudiadas por van Ginkel 1965; braquiópodos— clasificados por Winkler Prins) indican el Myachkoviense alto y Kasimoviense de la escala estratigráfica rusa.

INTRODUCTION

The Carboniferous of northern Palencia has long been known to contain alternating marine and continental strata, and recent studies have proved the presence of a wide range of different facies. They have also shown that ages ranging from Viséan to Stephanian B are present in a number of successions separated by rather short-lived breaks due to major tectonic movements. The successive basins may not have been entirely coincident, but certain features re-appeared at different times in the geological history of the area and a certain degree of permanence of the underlying causes of subsidence may therefore be suspected.

In the present paper a general discussion is presented of the succession which formed in northern Palencia after widespread movements of the Leonian tectonic phase, of late Westphalian D age. These movements, which produced folding and faulting in neighbouring León, only resulted in uplift and normal faulting in Nth. Palencia. The succeeding deposits are mainly marine, with occasional coals and other continental sediments, and provide varied faunas as well as floras of upper Westphalian D and lower Stephanian (*sensu lato*) ages, in a total succession of some 5,000 metres. This succession probably represents the most complete sequence of lower Stephanian strata in western Europe, with the nearest comparable sequence occurring in the Donbass of the Ukraine, U. S. S. R. In addition, the exceedingly varied fossil content of the northern Palencia sequence enables correlation between the West European and Russian stages and as a result northern Palencia must be regarded as a key area for stratigraphic studies.

Its special importance for chronostratigraphic classification of the Upper Carboniferous in western Europe lies in the continuity of sedimentation from late Westphalian D through «Cantabrian» to Stephanian A. Westphalian D and Stephanian A were described from the Lorraine and St. Etienne (Loire) coalfields in France. The lower Stephanian in Saar/Lorraine lies disconformably on Westphalian D, and there are clear indications that this disconformity is associated with an important time gap (Germer *et al.* 1968, Bouroz *et al.* 1970). In the St. Etienne coalfield the type Stephanian A lies unconformably on basement rocks. A correlation with lower Stephanian strata in northern Palencia (Wagner 1966[c], Bouroz *et al.* 1970) indicates that only the upper part of the lower Stephanian (*sensu lato*) in this area corresponds to Stephanian A. The strata intercalated between upper Westphalian D and Stephanian A have been assigned to a special chronostratigraphic unit, the Cantabrian Stage (on the assumption that the Stephanian will be recognized as a Series).

This Cantabrian Stage (Wagner 1966[b,c], 1969) should be based on a well studied stratotype, with its limits established in relation to those of the adjoining stages, Westphalian D below and Stephanian A above. With this aim in view, the basin which received sediments of Cantabrian age in Northwest Spain has been the subject of several recent investigations; one of these being the one carried out by the present writers. It should be noted that the data presented in the present paper will have to be evaluated and compared with those available from other areas in western Europe before a binding decision on the limits and stratotypes of lower Stephanian stages can be taken by the Subcommission on Carboniferous Stratigraphy of the IUGS Commission on Stratigraphy (see Postscript on page 599).

The present investigation is based on the detailed logging of stratigraphic sections to the scale of 1 : 100 and the collection of floras and faunas capable of providing the elements of correlation. At the same time, the more obvious sedimentological detail has been recorded for a better understanding of the development of the basin. This has also proved an aid in local correlation.

Only the first 2,500 metres of deposits have thus far been investigated in detail, i. e. that part of the succession which is found in the Casavegas Syncline (text-figs 1, 10). Of the higher part of the succession only the Stephanian A coal-bearing sequence at Barruelo, from the Carboneros Member upwards (text-fig. 11), has been studied in detail. The latter sequence has been studied previously by the first writer in collaboration with Mr. F. J. VILLEGAS. The 1 : 100 sections measured in the Casavegas Syncline have been reduced to 1 : 1,000 (text-figs 3, 7), although examples are given of sections reproduced to the original scale (text-figs 4, 5, 6, 8, 9 and 12). More general sections (scale 1: 20,000) are given in the correlation diagram of text-fig. 11, which makes use of the successions logged in the Casavegas Syncline as well as those published by NEDERLOF (1960: Redondo Syncline) and WAGNER & WINKLER PRINS (1970: Barruelo area). Recent investigations in the San Salvador area by the present writers are discussed in the text, but not illustrated as detailed sections.

Parts of the succession studied by the present writers were recently published by READING (1970), as part of a sedimentological investigation of the Upper Carboniferous rocks in Northwest Spain. His interpretation of sedimentary facies provided a most useful check on the records kept by the present writers.

The Upper Carboniferous rocks in northern Palencia were mapped most recently by NEDERLOF (1960), WAGNER (1960) and DE SITTER & BOSCHMA (1966). The comprehensive geological map compiled by the latter authors was originally used as a base for the map of the Casavegas Syncline, given here as text-fig. 1, but it proved too inaccurate to be reproduced without extensive modification. DE SITTER & BOSCHMA had failed to recognize the widespread Leonian disconformity in northern Palencia and they drew an arbitrary boundary between «Westphalian» and «Stephanian». This line only rarely coincided with the disconformity, and is therefore misleading. DE SITTER & BOSCHMA also described a number of «basins», on the assumption that major faults in the area would reflect ridges in the basement and thus limit sedimentary basins. This assumption has proved to be incorrect for the post-Leonian succession reported in the present paper and has no basis in observed fact anywhere in the area.

Elements of stratigraphic dating are provided by land plants (identified by the first writer), fusulinid foraminifera (VAN GINKEL 1960, 1965), and brachiopods (identified by Dr. C. F. WINKLER PRINS, as a personal communication). Other fossil remains include lamellibranchs, echinoderms, bryozoa, gastropods, sponges, trilobites, ostracodes, corals, algae, conodonts, fish teeth, orthoconic nautiloids and very occasional coiled nautiloids and goniatites. Most of these varied faunal remains have not yet been studied. However, a single goniatite has been described by WAGNER-GENTIS (1971), coral identifications were made available by Dr. G. E. DE GROOT (pers. comm.), sponges were studied by Dr. W. J. E. VAN DE GRAAFF (pers. comm.), some preliminary identifications of trilobites were provided by Dr. J. GANDL (pers. comm.), and non-marine lamellibranchs were studied by EAGAR & WEIR (1971).

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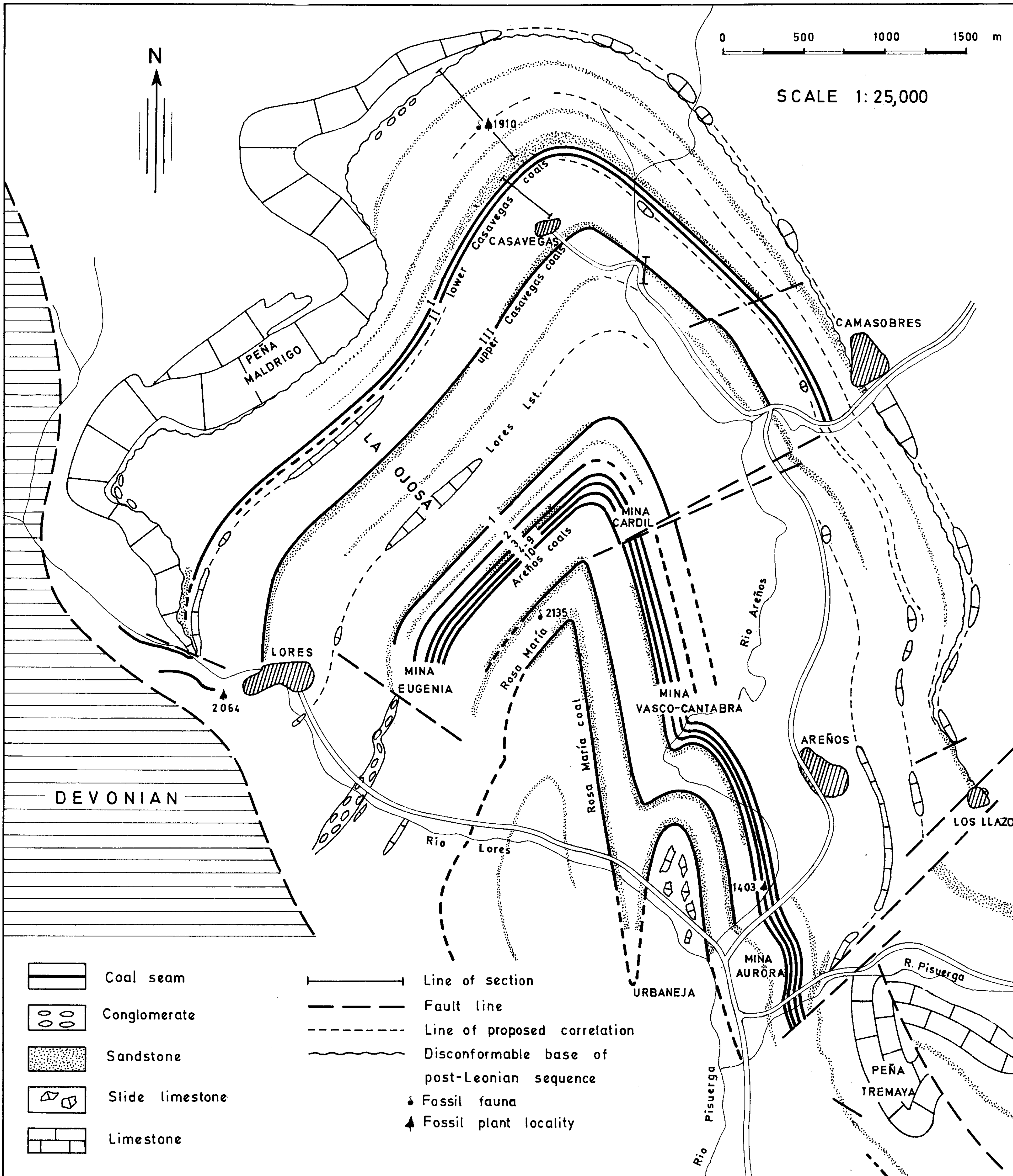


Text-fig. 1.—Geological map of the Casavegas Syncline. *Erratum:* Seam 10 of the Areños coals is the one below loc. 2135. The seam marked as no. 10 is, in fact, seam no. 9.

appreciation to Mr. R. C. Boud (University of Leeds) for professional assistance with drawing a number of the text-figures reproduced in the present paper. They are most grateful for the fossil identifications provided by Drs. C. F. Winkler Prins and G. E. de Groot (Rijksmuseum van Geologie en Mineralogie, Leiden), Dr. W. J. E. van de Graaff (University of Leiden), and Dr. J. Gandl(University of Würzburg). They are also indebted to Dr. A. Bouroz (Charbonnages de France) for identifying and collecting samples of cinerites which open up new vistas of a detailed regional and inter-regional correlation. Drs. D. G. Jones and P. G. Morris (University of London), and Mr. A. Méndez (University of Madrid) are thanked for assistance with measuring sections in the field. Mr. E. Muñíz most helpfully provided a mechanical digger for most of the La Ojosa section and assisted with mine data. The authors are extremely grateful for his cooperation and that of the Distrito Forestal de Palencia which allowed the digging of trenches. Finally, they acknowledge with pleasure the stimulating discussions with Dr. W. J. E. van de Graaff, whose study of the pre-Leonian succession in northern Palencia provided a usuful complement to the present investigation.

STRUCTURAL SETTING

The post-Leonian succession in northern Palencia has been folded into a number of NW-SE striking synclines, isoclinal or near-isoclinal, with the axial planes dipping towards the NE. The most continuous structure is formed by the isoclinal syncline which extends from the Barruelo region in the SE to the Redondo Valley area in the NW (see text-fig. 10). It is mainly the overthrust NE flank that is preserved of this structure which is limited to the SW by a major fault. In the Barruelo area this fault has been shown to consist of a normal fault emplaced on the site of an overthrust formed earlier in the same folding phase (Wagner & Winkler Prins 1970, text-fig. 2). After an anticlinal structure west of the syncline in the Redondo Valley, the post-Leonian succession crops out again in the Casavegas Syncline (top left of the map of text-fig. 10), which is near-isoclinal and which proved to contain the earliest post-Leonian deposits. It is this syncline which has been investigated in detail by the present writers (see text-fig. 1). The Casavegas Syncline passes southwards into E-W striking rocks of the Castillería Syncline, a structure which probably consists of a cross-fold superimposed on the plunges of NW-SE trending folds between the Redondo and Casavegas synclines. A different structural interpretation has been proposed for the Castillería Syncline by de Sitter & Boschma (1966, p. 226).

Post-Leonian strata are also represented in the Guardo-Cervera coalfield which strikes from just south of Cervera de Pisuerga to Guardo in a NE-SW and then E-W direction. The north-eastern part of this area of post-Leonian strata is shown on the lower left of the map of text-fig. 10. Apart from some incidental fossil collecting, this area has not been studied by the present writers, whose investigation is limited thus far to the Barruelo/Redondo, Casavegas and Castillería synclines in the northern part of the general region.

The structures in post-Leonian rocks were formed during the Asturian phase of folding which can be dated accurately in northern Palencia, where the Stephanian

A measures of Barruelo are overlain with angular unconformity by late Stephanian B strata (WAGNER 1966[d], p. 39, Pl. 6; WAGNER & WINKLER PRINS 1970, text-fig. 2, Pl. II). The Barruelo/Redondo Syncline and, by comparison, the Casavegas and Castillería synclines, were therefore produced by the Asturian fold movements during early Stephanian B times.

These Asturian structures were probably modified to some extent by later movements of Permian age, which folded the unconformable Stephanian B strata (Peña Cildá Formation). The latter are overlain unconformably by Triassic rocks at the base of a full Mesozoic succession which was folded by relatively slight Alpidic movements into a large, asymmetric anticline with attendant small scale thrusts and transcurrent faults.

POST-LEONIAN SUCCESSION IN NORTHERN PALENCIA

For some time the conviction has grown that the post-Leonian basin in northern Palencia gradually expanded its area in the course of lower Stephanian times (*sensu lato*). The most complete succession was apparently developed in the most northerly part of the area, and the stratigraphic investigation was therefore started in the region of Casavegas (text-fig. 1). The first 825 m of strata were measured along the road which leads from Casavegas north-westwards to Caloca in the province of Santander, and subsequent deposits, up to 917.50 m above the base of the succession at Casavegas, were studied in a road section near the bridge 500 m SE of the village. The lines of sectioning are drawn on the map of text-fig. 1, and the complete log (simplified) is presented in text-fig. 3. The succession was followed upwards by a long section measured on the crest of the hill which separates the land belonging to the village of Casavegas to the north-east from that of Lores to the south-west. This is the La Ojosa section (text-fig. 1) which is published in text-fig. 7 from the Lores Limestone upwards through the Areños coals into the Rosa María coal horizon. Below the Lores Limestone an additional sequence was measured at La Ojosa down to the Casavegas coal III. This sequence is discussed in the present paper but no graphic log is presented due to the fact that this necessary overlap with the Casavegas section was studied more recently and after the logs had been drawn. Altogether, up to the Rosa María horizon, some 2,140 m of strata have been measured in detail in the western limb of the Casavegas Syncline (text-figs. 7-9). In the eastern limb, west of the area of the abandoned Mina Aurora, a further 140 m were added to the sequence from the Rosa María horizon upwards.

Higher parts of the succession crop out to the south and east of the Casavegas Syncline, and these are presently being investigated. The preliminary results of the more recent investigation are discussed in the present paper, but no detailed sections are available as yet. A tentative correlation with the Barruelo region in NE Palencia, and the Redondo Syncline, east of the Casavegas Syncline, is presented in text-fig. 11. More recent information, obtained since the correlation diagram of text-fig. 11 was drawn, tends to modify this correlation slightly (see the discussion on page 580).

The detailed succession measured in different parts of the Casavegas Syncline, will be discussed in the following chapters.

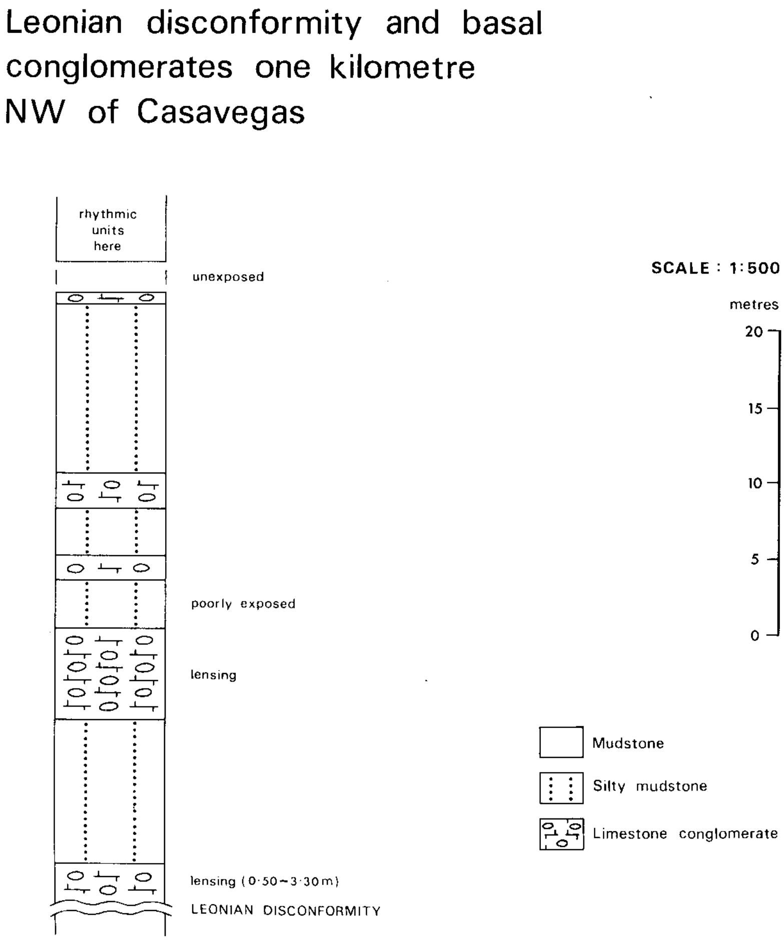
Casavegas / Caloca road section near Casavegas.

The earliest post-Leonian deposits in northern Palencia occur in a small area NW of the village of Casavegas (text-fig. 1). This area was mapped in outline by DE SITTER & BOSCHMA (1966), who placed the boundary between Westphalian and Stephanian A at an horizon containing limestone lenses, which passes a little north and north-west of Casavegas. This boundary appears to be arbitrary and a more detailed examination of the succession NW of Casavegas has, in fact, shown the presence of a stratigraphic break further down the succession, at some 70 metres above an important limestone horizon (i. e. the Maldrigo Limestone of VAN GINKEL 1960). This break is mappable throughout northern Palencia and corresponds to the Leonian disconformity, which is associated with uplift and normal faulting in this area. The Leonian disconformity near Casavegas does not coincide with the Westphalian / lower Stephanian boundary, the latter being some way up the post-Leonian succession. Unless the base of the lower Stephanian is placed, by definition, at a specific marker band in the succession at Casavegas, the Westphalian / Stephanian boundary is not mappable in this region. In any case, the arbitrary limit shown on DE SITTER & BOSCHMA's map is too high in the local succession to coincide, even approximately, with the Leonian disconformity, and too low for an approximation to the upper limit of the Westphalian D.

Basal conglomerates.

The Leonian disconformity NW of Casavegas is characterized by the presence of strongly lensing limestone conglomerates, the most important exposure of which is found 1 km NW of the village, in a valley leading out from Casavegas in a NNW direction. Five conglomerate bands, totalling 13.90 m, have been found at this locality (text-fig. 2), but a few hundred metres NNE along the strike these wedge to 0.50 m thickness (text-fig. 4). In the locality with maximum development of these limestone conglomerates, the basal one is seen to cut obliquely through underlying mudstones at an angle of *ca.* 5° to 10°. This angle may represent the side of a submarine channel and does not necessarily provide proof of tilting prior to the deposition of the basal conglomerate. The base of the basal conglomerate is irregular. The following description of this and succeeding conglomerates at the base of the post-Leonian succession NW of Casavegas is provided by Dr. D. G. JONES (personal communication):

«The conglomerates show considerable variation in the size of phenoclasts, the largest being of boulder size, i. e. in excess of 20 cm. The bulk of the phenoclasts, however, range between 5 and 10 cm and are predominantly pebbles of limestone set in a calcareous matrix with subordinate amounts of small detrital quartz grains, rarer flakes of muscovite and traces of argillaceous and carbonaceous material. Rare pebbles of coal and chert also occur. The phenoclasts are mainly of calcilutite,



Text-fig. 2.—Basal conglomerates of the post-Leonian succession in the valley north-west of Casavegas and a little over one kilometre from the village.

but some calcisiltites occur as well. The calcilutite phenoclasts often show grumous texture and contain fusulinid foraminifera, brachiopod shell fragments, bryozoa, crinoid ossicles, solitary rugose corals and calcispheres. Recrystallization (in the sense of FOLK 1965) is widespread in the larger calcilutite phenoclasts and probably occurred prior to erosion of the parent limestone and subsequent incorporation into the conglomerate. However, the coarse mosaic development consequent on recrystallization does not prevent recognition of the primary lithology. The smaller fragments

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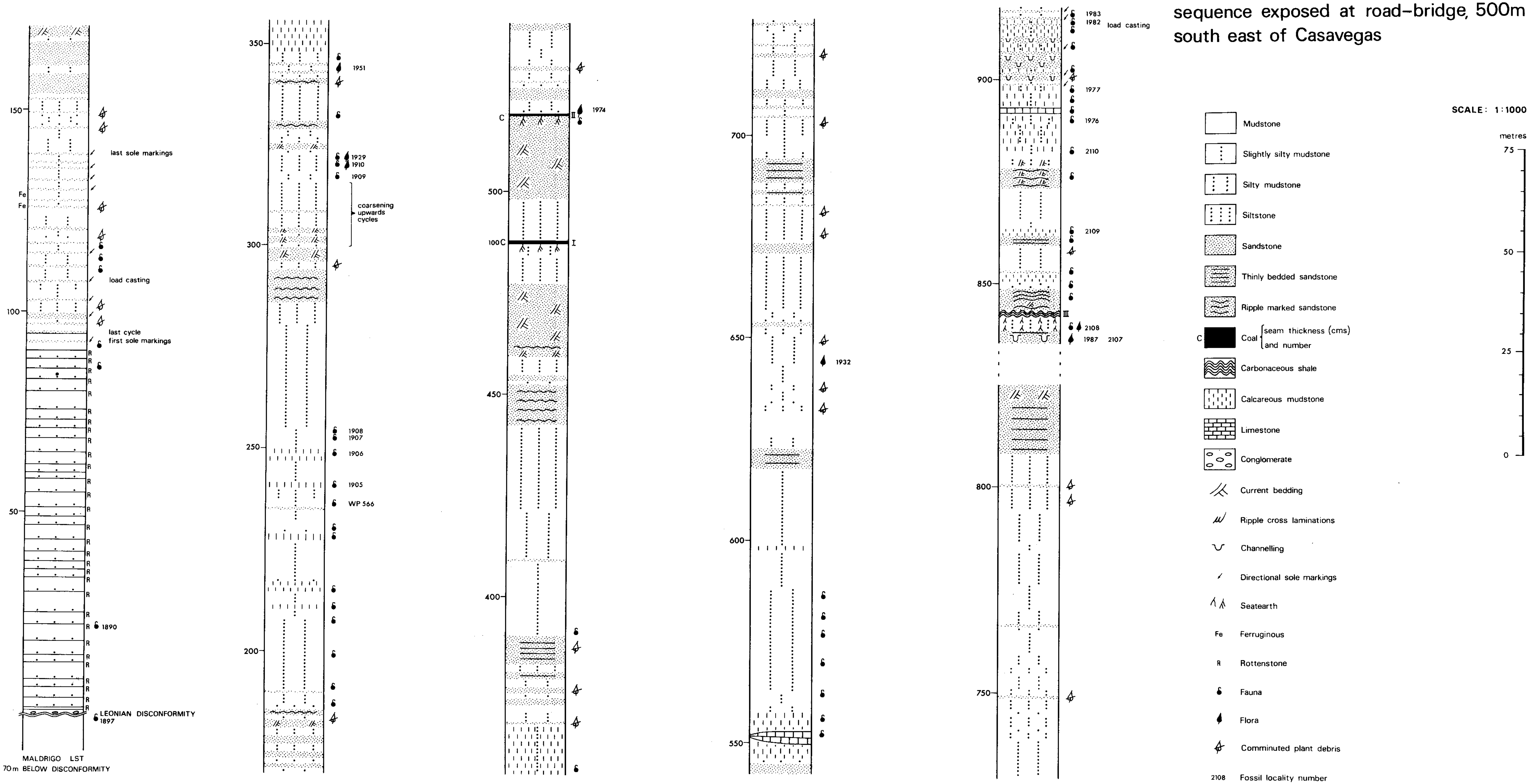
Text-fig. 3.—Stratigraphic section at scale 1:1,000 of the post-Leonian succession near Casavegas. Most of the section (up to 825 m) has been measured along the Casavegas/Caloca road, but the upper part corresponds to the sequence exposed along the Casavegas access road near the bridge at 500 m SE of the village. Rozo Formation up to 94 metres above the disconformity. The remainder of the section belongs to the Ojosa Formation.
Erratum: For III (Casavegas coal III at 842 m) *read* IV.



Section from Leonian discontormity to sequence exposed at road-bridge, 500m south east of Casavegas in the conglomerates are often difficult to interpret as phenoclasts or intraclasts. Recrystallization and syntaxial overgrowth occur where they were formed from skeletal fragments. The latter are well preserved in the case of algae such as *Komia* and *Macroporella*, and they often show little evidence of violent current action. Some of the algal growth may thus have been encrustations contemporaneous with the accumulation of the conglomeratic material. The main cementing material is ordinary sparry calcite with subordinate dolomite and pyrite. The slight development of secondary (vein) dolomite is post-depositional, i. e. post-early diagenetic, as it affects calcite veins which are probably of tectonic origin, being related to joint development in the conglomerate. The presence of encrusting marine algae shows that the conglomerate was formed in a marine environment of shallow water habitat. The presence of exogenetic pebbles of coal and limestone shows that this is not an intraformational conglomerate and that it was linked to uplift and erosion in a nearby area. Probably, the conglomerate is to be considered as being the result of uplift with shallowing allowing the spread of marine beach gravels seawards into shallow water.»

It is noted that the sorting of the pebbles, though generally poor, is slightly better in the second conglomerate than it is in the first. Pebbles in the basal conglomerate show a general range of 3 to 130 mm, whilst those of the second conglomerate range in size from 2 to 50 mm. The third limestone conglomerate has a sandy-shaly matrix and poorly sorted pebbles, up to 100 mm in diameter. The fourth limestone conglomerate, also with a sandy-shaly matrix, contains fragments of fossils and rare pebbles of coal interspersed with predominant limestone pebbles which are quite angular. The fifth conglomerate found in the section of text-fig. 2 shows angular limestone clasts ranging in size from 1 to 15 mm, and fossil fragments in a sandy-shaly matrix. After two metres of unexposed section a succession of small rhythmic units follows upon the limestone conglomerates.

The presence of different limestone types among the pebbles recorded and in particular coal pebbles, indicate erosion of rocks which are not in the immediate substratum of the conglomerates (compare the section of pre-Leonian strata as measured by VAN DE GRAAFF 1971, text-fig. 4: Casavegas Section). The uplift associated with the Leonian movements thus provoked the denudation of rocks which are not presently seen in the Casavegas area but which are also unlikely to have been very far away. Limestone pebbles do not, on the whole, resist a long transport. There is nothing to suggest that the limestone conglomerates north-west of Casavegas would have been deposited in a subaerial environment and it may be considered likely that the denudation products came from a nearby area, and that these were channelled into the newly formed sedimentary basin.

The geographically restricted nature of the post-Leonian basin near Casavegas is shown by the fact that its first deposits were formed in what appears to have been a local basin sag (text-fig. 1). A structure of this kind is strongly suggested by the notable flexuring of the Maldrigo Limestone, underlying the post-Leonian succession, which occurs west of Casavegas. A similar basin sag, of even smaller dimensions, occurs north-west of Lores (text-fig. 1) and it appears that the initial basin consisted of these local downwarps of strictly limited extent geographically. There is additional evidence for vertical movements in the substratum of the post-Leonian succession in the general area, and this will be discussed later in this paper.

The time interval involved in the Leonian disconformity near Casavegas may have been relatively short. The Maldrigo Limestone has been dated by VAN GINKEL (1965, Appendix 1 : loc. P 7) as either upper Podolskian or lower Myachkovian. It probably equates with the Sierra Corisa Limestone Formation, of Westphalian D age (WAGNER & WAGNER-GENTIS 1963; VAN DE GRAAFF 1971). This limestone formation lies at least 900 m above strata attributed to lower Westphalian D on floral remains, and may thus represent lower to middle Westphalian D. The sequence above the disconformity belongs to the upper Westphalian D (see later in this paper), and, therefore, the time gap appears to be small. It is also noted that the mudstones underlying the limestone conglomerate in the Casavega/Caloca road section (text-fig. 4) show a rhythmic disposition; each rhythmic unit consisting of fine siltstone followed by mudstone and calcareous mudstone (often weathering to rottenstone). The same kind of rhythmic unit occurs above the conglomerates, after the disconformity. It thus seems that the sedimentary conditions operating below the disconformity were only temporarily interrupted and returned quickly after the uplift.

Along the road leading out from Casavegas to Caloca (in a north-western direction) a well exposed stratigraphic section has been measured from the Leonian disconformity upwards, with a total thickness of 829.50 m. This succession, measured to the 1 : 100 scale, has been reduced and simplified to 1 : 1000 (text-fig. 3). The basal part of the succession is reproduced in more detail (text-fig. 4).

Rhythmic units.

Eighty small rhythmic units have been measured in an interval of 94.30 m of strata at the base of the post-Leonian section. They vary in thickness from 0.15-4.20 m, and have fine yellow siltstone at the base, bluish grey mudstone in the middle and brown rottenstone at the top. The mudstones and calcareous mudstones (rottenstones) are generally fossiliferous and contain the remains of lamellibranchs, orthoconic nautiloids, goniatites, small brachiopods, crinoids, ostracodes and bryozoa. Only one goniatite has been identified thus far, viz. *Boesites eotexanus* WAGNER-GENTIS (loc. 1890 — WAGNER-GENTIS 1971). The relative abundance of pelagic elements and the fine grain of the sediments are both indicative of a rather low rate of sedimentation. The sharp contact between siltstone beds and the underlying calcareous mudstones (rottenstones) in successive rhythmic units marks the sudden influx of coarser terrigenous material at intervals which, in the case of a newly re-established basin, may well be found to represent pulses of downwarp (and/or corresponding upwarp of an adjoining land area). The diminishing grain size from bottom to top in each rhythmic unit would mark the period of tectonic quiescence following each of these pulses. The adjoining relief bordering the basin of sedimentation was probably rather mature; otherwise, the grain size of the sediment would probably have been larger. There is

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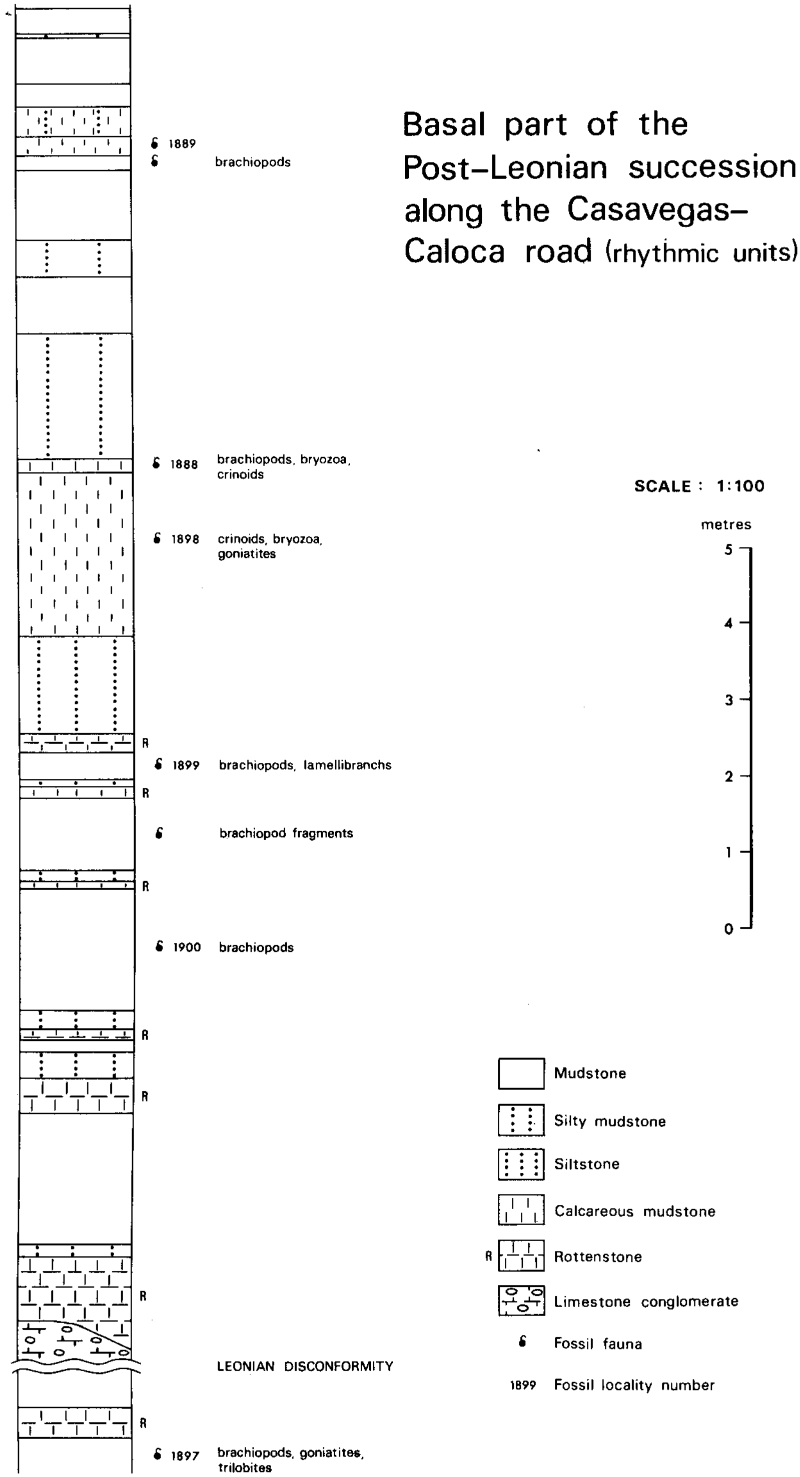
Text-fig. 4.—Rhythmic, fining upwards sequences of the Rozo Formation at the base of the post-Leonian succession NW of Casavegas.



Basal part of the Post-Leonian succession along the Casavegas-Caloca road (rhythmic units) little limestone in this succession, although the rottenstones were probably fairly calcareous. Only at 51.30 m above the disconformity are there two small lenses of detrital limestone. The lower one, some 0.10 m thick, shows calcirudite with calcarenite at the top in an apparently graded sequence. The upper one, at 52 m above the disconformity, is a somewhat finer calcirudite, some 0.15 m thick. Both limestones pass laterally into calcareous mudstone within a single outcrop.

Graded and current bedded sandstones.

The sequence of rhythmic units passes gradually upwards into a succession of mudstones with occasional thin, fine-grained sandstones showing directional sole markings, signs of grading and sometimes ripplemarks at the top. The occasional influx of graded sandstone with sole markings indicates a probable steepening of the basin slope. The top of the first thin bed of graded sandstone, 0.02 m thick, occurs 2.60 m below the top of the last rhythmic unit, and the change in sedimentation therefore appears to have been gradual. The last evidence of directional sole markings was found at 140 m above the disconformity. A probable shallowing of the basin is indicated above this horizon by thinly bedded siltstones and sandstones culminating in current bedded sandstone at 183 m above the disconformity. Throughout this episode of shallow marine basin, as well as in the previous unit with occasional sole markings, the presence of comminuted plant debris is noted, and at 96.30 m (loc. 1904) a fragment of *Callipteridium jongmansi* (P. BERTRAND) has been collected.

Quiet marine basin.

The current bedded sandstone at 183 m is followed by ripplemarked sandstone and siltstone with ripple cross-lamination, which forms a transition to silty mudstones and slightly silty mudstones containing calcareous mudstone horizons with abundant marine fossils. At 187 m above the disconformity there is, therefore, an apparent change from shallow marine basin to quiet marine basin, where mud takes the place of sand and where calcareous horizons mark temporary lulls in the sedimentation. These calcareous horizons are very fossiliferous, with predominant brachiopods, crinoids, bryozoa, gastropods and lamellibranchs, but also trilobites, corals, ostracodes and even a few fragments of goniatites. From localities WP 566, 1905, 1906 and 1907 (text-fig. 3) the following brachiopods were recorded, after identifications by Dr. C. F. WINKLER PRINS (personal communication):

Karavankina sp.
Karavankina rakuszi WINKLER PRINS.
Juresania sp.
Alexenia sp. ex gr. *A. reticulata* IVANOVA.
Kozlowskia sp.
Cancrinella sp.
Tornquistia sp.

Rhipidomella sp.
Schizophoria sp.
Attenuatella aff. *frechi* (SCHELLWIEN).
Zaissania sp.
Phricodothyris sp.
Martinia sp.

According to WINKLER PRINS (*in litt.*), the presence of *Attenuatella* aff. *frechi* would point to a Kasimovian age rather than Myachkovian, but this conclusion is tentative and subject to more precise information becoming available on the ranges of the various brachiopod species.

Coarsening upwards sequences.

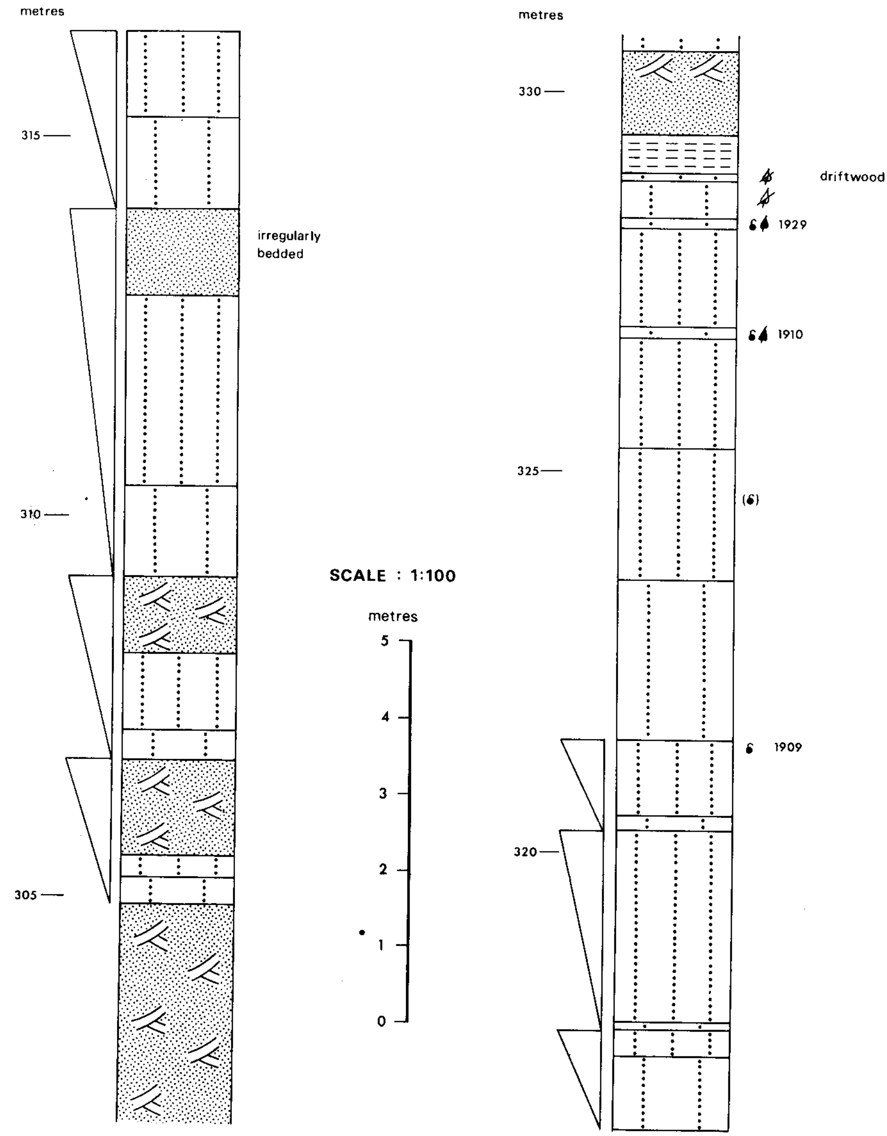
At 287 m above the disconformity ripplemarked sandstones followed by current bedded sandstones mark another shallowing of the basin. They are succeeded by seven short sequences which coarsen upwards (text-fig. 5) and which may indicate infilling of the basin after intermittent subsidence. The general succession continues to be shallowing, with emergence at certain intervals where freshwater to brackish lamellibranchs are found (at 318, 321, 324.40 and 324.80 m). Well preserved land plants are found as well at the latter two localities (loc. 1910 at 324.40 m, and loc. 1929 at 324.80 m). The lamellibranchs have been identified by EAGAR & WEIR (1971) and the plants by one of the present authors (R. H. W.). The total flora consists of the following elements which form a late Westphalian D assemblage (or early Cantabrian ?):

Neuropteris planchardi ZEILLER.
Neuropteris ovata HOFFMANN.
Neuropteris scheuchzeri HOFFMANN.
Callipteridium sp. indet.
Pseudomariopteris ribeyroni (ZEILLER) DANZÉ-CORSIN.
Lobatopteris (Pecopteris) vestita (LESQUEREUX) WAGNER (very abundant).
Polymorphopteris (Pecopteris) polymorpha (BRONGNIART) WAGNER.
Pecopteris sp. indet.
Sphenophyllum emarginatum BRONGNIART.
Annularia stellata (VON SCHLOTHEIM) WOOD.
Calamites suckowi BRONGNIART.
Lepidostrobus sp. indet.

The faunal remains are as follows (after EAGAR & WEIR 1971):

Anthraconaia spathulata WEIR (loc. 1910).
Anthraconaia sp. cf. *persulcata* WEIR s. l. (1910).
Anthraconaia sp. cf. *arenacea* (DAWSON) ROGERS (1910, 1929).
Naiadites obliquus DIX & TRUEMAN (1929).
? *Myalina* (or *Naiadites*) sp. (1929).

Coarsening upwards sequences along the Casavegas–Caloca road



Silty mudstone

Siltstone

Shale

Sandstone

Current bedding

Coarsening upwards sequence

1909 Fossil locality number

Fossil fauna

Fossil flora

Comminuted plant debris

Brackets denote uncommon fauna

According to the cited authors (*loc. cit.*), these are freshwater faunas which probably lived in a prodeltaic environment, covered at times by partly saline water. *Anthraconaia* commonly appears when marine conditions are on the wane and it may be a brackish rather than a purely freshwater element. It should be noted that, despite the presence of well preserved plant fossils associated with the lamellibranchs, there is no evidence of root beds. The vegetation is therefore not entirely *in situ*. Altogether, the impression is created of marginally marine to freshwater deposits. They represent the first horizon of emergent non-marine facies in the post-Leonian succession. Above loc. 1929 with identifiable plants and lamellibranchs, only unidentifiable driftwood is found in a siltstone band, and the next deposits are shales and sandstone, current bedded at the top.

This horizon of non-marine facies can be traced east- and south-eastwards (text-fig. 1), where drifted plant remains are found again in a locality along the road to Camasobres, at 120 m from the village (loc. 2159):

Neuropteris ovata HOFFMANN.
Alethopteris sp.
Sphenopteris sp.
Lobatopteris vestita (LESQUEREUX).
Sphenophyllum sp.
Calamites sp.

Further south-eastwards the horizon becomes sandier and a seat-earth is found established at the top of the local sandstone (text-fig. 1). A tentative correlation allows this sandstone to be traced to a more prominent sandstone horizon at Los Llazos.

South-west of loc. 1910 (and 1929) in the Casavegas/Caloca road section, the current bedded sandstones preceding the coarsening upwards sequences below the plant and lamellibranch horizon, can be followed along the strike to the crest of the hill which separates the villages of Casavegas and Lores (text-fig. 1). There they occur near or at the base of the local post-Leonian succession, outside the area of the initial basin sag at Casavegas. Further south-westwards another basin sag is clearly marked in the pre-Leonian Maldrigo Limestone, and this horizon may again be some distance from the base of the post-Leonian succession. Further towards Lores the basin margin was apparently established during the first period of existence of the post-Leonian basin, and the horizon of loc. 1910 probably disappears against this margin.

Renewed transgression.

A gradual deepening of the basin seems to be suggested by the sequence from a point 327 m above the disconformity. Sandy shales alternate with siltstone and a

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Text-fig. 5.—Detail of the coarsening upwards, regressive sequences found at 305 m above the base of the post-Leonian succession in the Casavegas/Caloca road section (compare text-fig. 3). Ojosa Formation.

ripplemarked sandstone, which is followed by further siltstone and sandy mudstone containing crinoid ossicles. These strata are succeeded by sandstones with ripple cross-laminations and siltstones with comminuted plant remains. At 346 m above the disconformity a thin shale contains the following plant fossils (loc. 1951 — R. H. W. *det.*):

Neuropteris ovata HOFFMANN.
Neuropteris scheuchzeri HOFFMANN.
Callipteridium (Praecallipteridium) armasi (ZEILLER) WAGNER.
Pseudomariopteris ribeyroni (ZEILLER) DANZÉ-CORSIN.

This is an assemblage of either late Westphalian D or early Cantabrian age.

Transgression and basin fill: coarsening upwards.

A 25 m interval of calcareous mudstone (quiet basin) is followed by thinly bedded sandstones with comminuted plant debris and some intercalated sandy mudstones. These are succeeded by another fairly long interval of mudstone and silty mudstone leading up into siltstones and ripplemarked, thinly bedded sandstones which in turn pass into thick, current bedded sandstone. These may be interpreted as two basin fill successions, with a gradual passage from finer to coarser terrigenous material and a more abrupt one between sandstone and overlying mudstone. It seems likely that intermittent downwarp of the basin caused rather sudden retreats of the shoreline, with the consequent deposition of finer sediments. The gradual infilling of the basin would then produce progressively coarser deposits as the shoreline advanced. The current bedded sandstone of the latest basin fill sequence recorded is followed by thinly bedded sandstones, siltstones and silty mudstones.

Lower Casavegas coals (I-II).

The silty mudstones were colonized by vegetation constituting the seat-earth of the first coal in the Casavegas succession (text-fig. 3). This coal is 1 m thick in the valley north-west of Casavegas where it has been worked on a very limited scale. Thinly bedded sandstones forming the roof of this seam are succeeded by current bedded sandstones, at the top of which Stigmarian rootlets penetrate the sandstone and form the seat-earth of the second Casavegas coal. This seat-earth represents the passage from marine to non-marine, since even the top part of the sandstone, just below the seat-earth, still contains marine fossils (crinoid ossicles). This succession, from the roof of Casavegas seam I to the top of seam II, represents another one of the regressive sequences which seem to characterize a large part of the post-Leonian succession in the Casavegas Syncline and which may be interpreted as repeated basin fill sequences formed after intermittent downwarp.

The seat-earth below Casavegas coal II contains a few fragments of fern foliage, i. e. *Lobatopteris vestita* (LESQUEREUX), in an old digging 400 m ENE of the village (loc. 2065). Further plant remains were collected due west of Casavegas in a locality of silty shales, which are the probable equivalent of 0.80 m of silty carbonaceous mudstone with abundant plant fragments, at 0.60 m above the second Casavegas coal. The following species were identified from the locality in the valley west of Casavegas (loc. 1974 — R. H. W. *det.*):

Neuropteris ovata HOFFMANN.
Neuropteris scheuchzeri HOFFMANN.
Callipteridium sp.
Alethopteris grandini (BRONGNIART) GOEPPERT.
Dicksonites cf. *pluckeneti* (VON SCHLOTHEIM) STERZEL.
Sphenopteris neuropteroides (BOULAY) ZEILLER.
Sphenopteris sp.
Sphenophyllum emarginatum BRONGNIART.
Sphenophyllum guerreiroi TEIXEIRA.

This assemblage indicates a late Westphalian D age.

Casavegas Limestone.

Alternating silty mudstones, shales, siltstones and sandstones with occasional comminuted plant remains and pieces of driftwood occur in the 25 m above the plant horizon of loc. 1974. No bedrock was reached subsequently in a trench dug along the Casavegas/Caloca road, but yellow calcareous mudstone was turned up by the spade. This calcareous horizon corresponds with a limestone lens at *ca.* 27 m above the second Casavegas coal, 400 m ENE of the village, and with a similar, though somewhat more important limestone lens at La Ojosa, 1.5 km SW of Casavegas. Corals collected in the latter locality (1886) were identified as *«Lonsdaleia» portlocki* (STUCKENBERG), a Podolskian and Myachkovian species of the Moscow Basin (personal communication by Dr. G. E. DE GROOT).

This Casavegas Limestone (VAN GINKEL 1960, Fig. 1) is developed in an irregular manner in different parts of the Casavegas Syncline (text-fig. 1). It occurs near the base of the local post-Leonian succession near Lores, and is traced in the eastern limb of the syncline to a locality west of Los Llazos.

The limestone and calcareous mudstone at this horizon inaugurate a long sequence of quiet marine deposits, consisting of mudstones with sporadic brachiopods and, at one particular level, also indeterminate cephalopods and trilobites. Thinly bedded sandstones, at 622 m above the disconformity, mark the beginning of a slightly more sandy sequence which contains comminuted plant debris at certain horizons and which may represent another shallowing of the marine basin. Identifiable plant remains were collected from a single bedding plane, at 647.50 m above the disconformity (loc. 1932 — R. H. W. *det.*):

Neuropteris ovata HOFFMANN var. *ovata.*
Callipteridium cf. *armasi* (ZEILLER) WAGNER.

Alethopteris robusta LESQUEREUX var. *robusta.*
Alethopteris kanisi WAGNER.
Lobatopteris vestita (LESQUEREUX) WAGNER.
Annularia sphenophylloides (ZENKER) VON GUTBIER.
Calamites schutzei STUR.
Sigillaria brardi BRONGNIART.

Hitherto, *Alethopteris robusta* var. *robusta* had only been recorded from Upper Pennsylvanian rocks in North America which are likely to equate with Westphalian D (compare WAGNER 1968, p. 132), and from late Westphalian D deposits in the Saar Basin (GERMER *et al.* 1968). Another variety of *Alethopteris robusta* was described from late Westphalian D strata in England (WAGNER 1968).

Upper Casavegas coals (III-IV).

Thinly bedded siltstones and sandstones, with intervals of silty mudstone, follow in a possibly littoral succession, interrupted again by generally somewhat less silty mudstones showing signs of bioturbation. This sequence is followed by another representing progressive shallowing, and consisting of thinly bedded siltstone passing into sandstone which becomes current bedded in the upper part, prior to a coal seam (Casavegas coal III) and its seat-earth. This coal has not been reached in the section measured at Casavegas, due to lack of exposure, but its presence is clear from a coal tip near the cemetery at the entrance to the village. Only poorly preserved plant fragments were collected from this tip (loc. 2070 — R. H. W. *det.*): *Mixoneura* sp., *Mariopteris* sp.

The same coal has been seen in the La Ojosa section, where it is 0.60 m thick. It is followed by another seam (Casavegas coal IV), 0.70 m thick, which correlates with carbonaceous shales and seat-earths in the section measured near the bridge 500 m SE of Casavegas (text-figs 3, 6). The corresponding part of the La Ojosa section, overlapping with the section at Casavegas, has been measured only recently and is not represented in the log figured of La Ojosa (text-fig. 7).

The upper Casavegas coals can be traced from La Ojosa south-southwestwards to the village of Lores, where abandoned small workings exist in these coals. South-west of Lores, a continuation of these coals is found in a somewhat crumpled succession which contains a richly fossiliferous plant locality (2064 — R. H. W. *det.*, see text-fig. 1):

Neuropteris ovata HOFFMANN.
Neuropteris scheuchzeri HOFFMANN.
Neuropteris sp.
Linopteris palentina WAGNER.
Linopteris sp. nov.?
Odontopteris sp.
Callipteridium (Praecallipteridium) jongmansi (P. BERTRAND) WAGNER.

Alethopteris ambigua LESQUEREUX (abundant).
Alethopteris grandinioides KESSLER var. *grandinioides*.
Alethopteris lesquereuxi WAGNER.
Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.
Sphenopteris neuropteroides (BOULAY) ZEILLER.
Sphenopteris dimorpha (LESQUEREUX) WAGNER.
Sphenopteris sp. (cf. *trigonophylla* BEHREND).
Pecopteris (Ptychocarpus) unita BRONGNIART.
Pecopteris sp.
Sphenophyllum emarginatum BRONGNIART.
Sphenophyllum guerreiroi TEIXEIRA.
Annularia sphenophylloides (ZENKER) VON GUTBIER.
Annularia stellata (VON SCHLOTHEIM) WOOD.
Sigillaria brardi BRONGNIART.

This assemblage is sufficiently complete to permit a reasonably accurate stratigraphic age determination. The most important element in this well preserved flora is *Callipteridium jongmansi*, which has been found here with fragments of pinnae of the penultimate order showing the presence of two intercalated pinnules on the penultimate rachis, in the top part of the pinnae. This represents a stage in evolutionary development below that recorded for *Callipteridium (Praecallipteridium) jongmansi* in basal Cantabrian strata (WAGNER *et al.* 1969, Pl. 2), which shows four to five intercalated pinnules in the apical part of pinnae on either side of the penultimate rachis. Consequently, the specimens from loc. 2064 at Lores are referred to late Westphalian D. All the other species found could occur as an assemblage in either late Westphalian D or lower Cantabrian rocks.

Section near the road bridge 500 metres SE of Casavegas

The succession measured along the Casavegas/Caloca road is continued after a small gap by a detailed section measured along the access road to Casavegas, near the road bridge 500 m SE of the village (text-figs 3, 6). The higher of the two seams of the upper Casavegas coals crops out in a small digging, and is found again on the other side of the valley. The measured section starts at 6.50 m below this seam, where very silty mudstones yield a flora composed of the following elements (loc. 1987 —R. H. W. *det.*):

Neuropteris scheuchzeri HOFFMANN.
Linopteris palentina WAGNER.
Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.
Sphenophyllum emarginatum BRONGNIART.
Lepidodendron sp.

This assemblage may be attributed to late Westphalian D.

There follows a massively bedded, well washed, quartzose sandstone containing mudstone pebbles and drifted tree trunks and branches. It shows evidence of channelling at the base. The bedding interval is approximately 25 cm, and the total thickness of this sandstone is 1 m. It is followed by 0.10 m of silty shale with drifted plant remains, among which the following could be identified (loc. 2107 — R. H. W. *det.*):

Neuropteris sp.
Mariopteris sp.
Sphenophyllum emarginatum BRONGNIART.
Calamites sp.

This plant bed is channelled into by another sandstone, 0.35 m thick, of similar characteristics to the previous one. A subsequent deposit of thinly bedded sandstone (1 to 5 cm bedding interval), alternating with micaceous siltstone, shows the presence of some drifted plant remains at its base. This unit, 0.60 m thick, is followed by a very silty, micaceous mudstone with occasional rootlets (0.20 m), very silty mudstone (0.30 m), sandstone (0.25 m), very silty mudstone with a few rootlets (0.10 m), and silty mudstone with abundant Stigmarian rootlets and drifted plant remains as well as rare shell fragments (0.65 m). Identifiable plant fossils were obtained from the first 20 cm (loc. 2108 — R. H. W. *det.*):

Neuropteris ovata HOFFMANN var. *ovata.*
Linopteris palentina WAGNER.
Alethopteris cf. *ambigua* LESQUEREUX.
Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.
Sphenopteris sp.
Pecopteris sp. (cf. *Lobatopteris viannae* (TEIXEIRA) WAGNER).
Sphenophyllum emarginatum BRONGNIART.

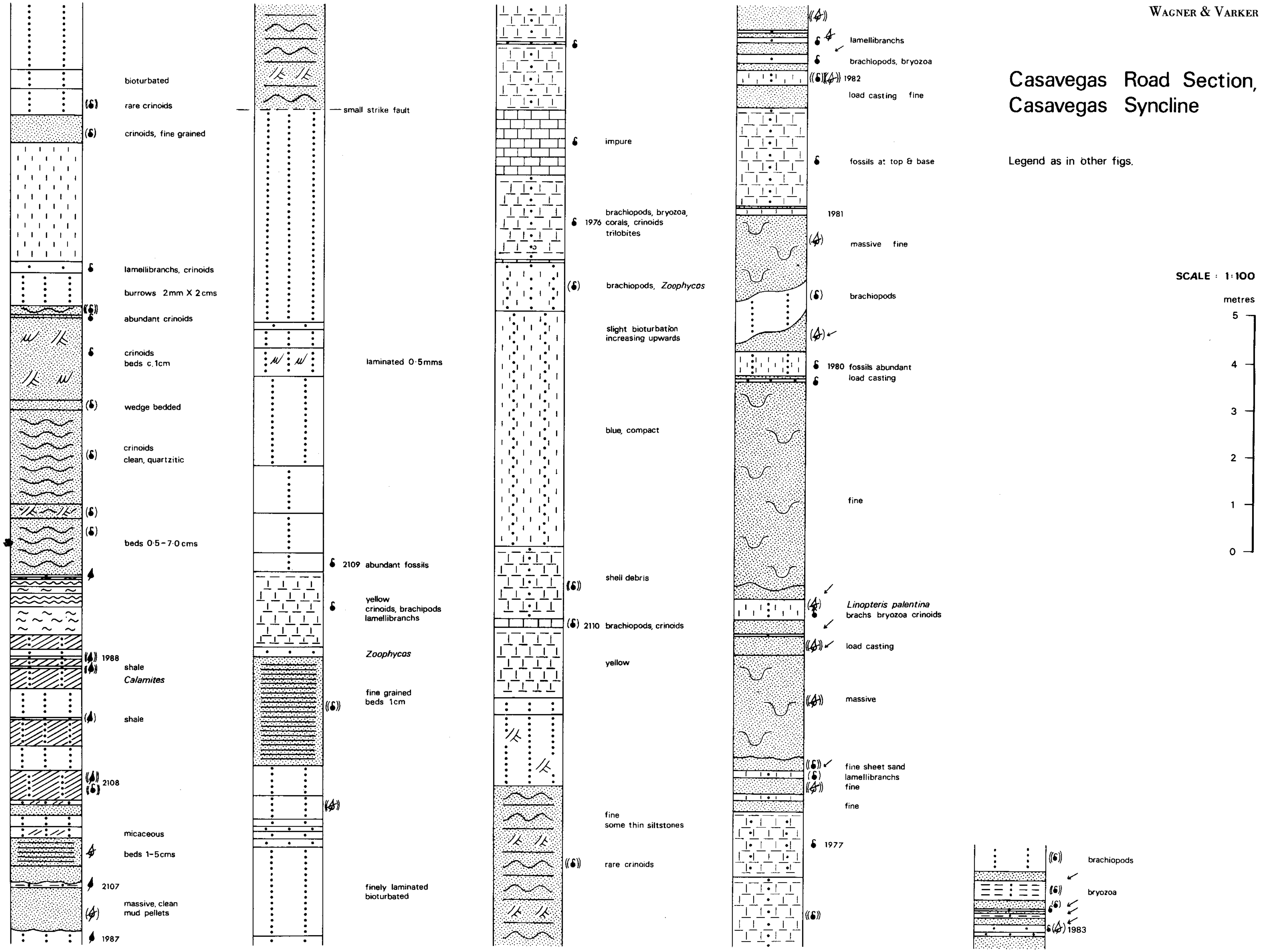
If the presence of *Lobatopteris viannae* could be confirmed, it would constitute the earliest record (uppermost Westphalian D) of this species, which is otherwise virtually restricted to the Stephanian (mainly Stephanian A and B).

Above this root bed with drifted plant remains there is an alternation of very silty mudstone, very silty and silty mudstone with Stigmarian rootlets and occasional plant remains, and, at one horizon, silty mudstone with a few rootlets and drifted plant remains (loc. 1988 — R. H. W. *det.*):

Callipteridium sp.
Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.
Pecopteris sp.
Sphenophyllum sp.

→

Text-fig. 6.—Detailed section (scale 1:100) of the rocks exposed near the road bridge at 500 m SE of Casavegas (compare text-fig. 3, upper part). Ojosa Formation.



Casavegas Road Section, Casavegas Syncline

Legend as in other figs.

This plant locality is followed by 0.30 m of silty mudstone with abundant Stigmarian rootlets, representing the seat-earth of Casavegas seam IV, which consists here of unproductive carbonaceous shales (0.62 m). These are overlain by 0.05 m of slightly silty shales with plant remains.

The whole complex of alternating root beds and plant-bearing mudstones and shales, with its culmination in a carbonaceous shale, represents the final continental stage of the regressive unit which was initiated in the top part of the Casavegas/Caloca road section. Deltaic sandstones at the entrance of Casavegas village fit the picture as the immediately preceding deposits.

Transgression.

Ripplemarked, thinly bedded sandstone, with occasional marine fossils, overlies the roof shales of the highest Casavegas coal. It marks a sudden transgression, a suddenness which is even more marked at a locality, 1150 m along the strike in a south-easterly direction, at the junction between the Casavegas and Camasobres roads (text-fig. 1). Here, the sandstone shows the carbonized remains of floated tree trunks at its base, and crinoid debris throughout. This «river-generated» sandstone (READING 1970, text-fig. 3, section 7) was apparently taken up by the transgression and deposited in a fully marine environment. In the measured section, the first 1.20 m of ripplemarked sandstone are followed in succession by 0.30 m of ripplemarked and current bedded sandstone, 2.00 m of well washed quartzose sandstone with ripplemarks, 0.20 m of wedge bedded sandstone, 1.75 m of thinly bedded (*ca.* 1 cm bedding interval) and faintly ripplemarked sandstone (ripple cross-lamination common), 0.05 m of very fossiliferous sandstone (crinoids), and 0.20 m of well washed, ripplemarked sandstone. Crinoid debris occurs throughout, but is particularly common in the 1.75 m interval and in the 0.05 m thick fossil band mentioned.

The transgressive sandstone horizon probably represents beach and estuarine deposits, the relatively coarse grain of the sediment being due to the suddenly increased gradient of the rivers, perhaps by shortening of the course and possible uplift of the drainage area.

Quiet marine basin.

More quiet marine conditions prevailed after the transgressive sandstone was laid down, either because of an increased distance from the shore or as the result of diminished relief in the drainage area. This sandstone is succeeded by very silty mudstone with vertical burrows (0.70 m); silty, ferruginous, calcareous mudstone with lamellibranch shells, crinoid debris and other animal remains, including an orthoconic nautiloid shell (0.25 m); sheared, ferruginous, slightly calcareous mudstone (2.50 m); fine-grained, slightly calcareous, ferruginous sandstone with crinoids (0.60 m); silty, micaceous mudstone, bioturbated, with rare crinoids (0.60 m); silty, bluish-grey, micaceous, bioturbated mudstone (0.40 m); silty mudstone (1.50 m); and silty mudstone, bioturbated, but finely laminated before bioturbation (1.90 m). These marine basin conditions are succeeded by a probably more shallow marine facies (marking a return to the regressive tendencies of earlier successions?), with occasional comminuted plant debris and thinly bedded sandstone. The following, rather silty deposits were measured: green siltstone (0.20 m); blue, silty mudstone (0.15 m); finely laminated siltstone (0.10 m); blue, silty mudstone (0.15 m); silty mudstone with rare comminuted plant debris (0.50 m); blue, silty, micaceous mudstone (0.65 m). They are succeeded by 2.35 m of thinly bedded, fine-grained, grey, micaceous sandstone.

A renewed transgression may be indicated by the gradually fining deposits following on from here: thinly bedded siltstones with *Zoophycos* markings (0.20 m); yellow, calcareous mudstone with abundant crinoids and also lamellibranchs, brachiopods, etc. (1.60 m); bluish grey, slightly silty mudstone with abundant fossils, mainly brachiopods, but also crinoids, lamellibranchs, bryozoa, etc. (0.40 m). Among the brachiopods, Dr. C. F. WINKLER PRINS (pers. comm.) recognized the following (loc. 2109):

Karavankina sp.
«*Horridonia*» cf. *incisa* (SCHELLWIEN).
Zaissania sp.

The presence of «*Horridonia*» *incisa* probably indicates Kasimovian rather than Myachkovian (compare WINKLER PRINS *in* WAGNER & WINKLER PRINS 1970).

This fossil band is succeeded by slightly silty mudstones (1.85 m), somewhat bioturbated in the upper part. These are followed by silty mudstone, blue-grey in colour and with spheroidal weathering (1.90 m), passing into laminated siltstones and very silty mudstones (5.65 m), the first siltstones showing signs of ripple cross-laminations. This coarsening upwards sequence is terminated by a complex of current bedded and ripplemarked sandstones and siltstones (7.50 m), showing increased shallowing of the marine environment. One of the current bedded sandstone intervals has yielded rare crinoid debris and it is clear that no emergence took place at the locality examined, even though the coast cannot have been far away.

Renewed transgression is indicated by the immediately following deposits, which consist of yellow calcareous mudstone (1.50 m), passing into dirty limestone (0.20 m — loc. 2110) with brachiopods and crinoids. Conditions of relatively slow deposition apparently lasted for some time, since calcareous mudstones of varying degrees of siltiness and one impure limestone, continue for 15.90 m. Fossils occur practically throughout. Loc. 1976 yielded remains of brachiopods, crinoids, trilobites, corals, bryozoa, ostracodes, lamellibranchs, etc. Among the brachiopods Dr. C. F. WINKLER PRINS (pers. comm.) recognized the following:

Crania sp. ex gr. *C. modesta* WHITE & St. JOHN.
Avonia (Quasiavonia) echidniformis (CHAO).
Krotovia? aff. *curvirostra* (SCHELLWIEN).
Karavankina sp.
Rhipidomella sp.

Brachythyrina sp.
Martinia sp.
Phricodothyris sp.
rhynchonellids.
strophomenid.
cf. *Neochonetes latesinuatus miaokouensis* (CHAO).
? *Globosochonetes* sp.

At the top of the calcareous mudstones, in loc. 1977, *Martinia* sp. and rhynchonellids have been identified by C. F. WINKLER PRINS. The assemblage is again of Kasimovian or Myachkovian age.

Sandstones with sole markings and scours.

A sudden influx of fine-grained sandstone (0.25 m), above loc. 1977, marks a change from the preceding calcareous mudstones. From here-on, there are frequent alternations of sandstone and slightly silty mudstone (or silty mudstone), which is often calcareous. The sharp contacts between mudstones and sandstones indicate a mass transport of the sand into a basin which was normally accumulating mudstones of the quiet marine basin facies. The mudstones, in fact, contain the same kind of fossils which characterize the localities mentioned earlier. The sandstones quite commonly show directional sole markings at the base —thus emphasizing the allochthonous nature of the deposit—, and also show signs of fairly large scours at the base of and within the sandstone masses. Comminuted plant debris is not uncommonly encountered in these sandstones (more seldom in the mudstones), and it appears likely that the sand was originally deposited nearer the coast. In keeping with the inferred mode of deposition, the sandstones are either massively bedded or appear as single massive units. Load casting is occasionally recorded at the base of the sandstone intervals, whilst grading is apparently absent.

The following brachiopods were identified by Dr. C. F. WINKLER PRINS from localities 1980, 1981 and 1982, in the intervening mudstones:

cf. *Karavankina paraelegans* SARYCHEVA.
Alexenia sp. ex gr. *reticulata* IVANOVA.
Kozlowskia sp.
Globosochonetes sp.
Neochonetes latesinuatus miaokouensis (CHAO).
Hustedia aff. *remota* (VON EICHWALD).
Zaissania sp.
Brachythyrina sp.

Other fossils include corals, bryozoa, crinoids, holothurians, trilobites, lamellibranchs, gastropods, orthoconic nautiloids and ostracodes. Amongst the trilobites Dr. J. GANDL (pers. comm.) identified *Ditomopyge* sp. aff. *productum*

Weber. The species *D. productum* is known from the highest Moscovian (Myachkovian) to the Gzhelian.

The total section measured in the road cutting near the bridge at 500 metres south-east of Casavegas is 82 m thick. The road bends at this point and on the other side of the bend, nearer the village (text-fig. 1), the same succession is found to have increased in thickness by one third. This dramatic expansion of the sequence deposited appears to be almost entirely due to increases in the thickness of mudstone intervals and may thus reflect a difference in the subsidence of the basin. Since the lateral distance involved is only some 150 m, it is clear that a basin margin must at one time have existed in the near vicinity. The south-easterly thinning of the sequence examined SE of Casavegas, is confirmed by the exposures found in the section where the access road to Casavegas branches off from the main road to Camasobres (text-fig. 1). This section, which has been described by Reading (1970, p. 16, section 7), shows a further decrease in the mudstone intervals. Mapping in the region between Camasobres and Casavegas (text-fig. 1) shows the gradual elimination of the lowermost deposits in the direction of Camasobres as well as some overall thinning in the same direction (certain units being more clearly affected than others which may have been developed with equal thickness throughout the area). The basin margin near Camasobres was temporary and the effects of diminished subsidence in this region were only operating at certain intervals in time.

La Ojosa section

The alluvial plain of the stream flowing southwards from Casavegas into the Río Areños (text-fig. 1) covers the continuation of the section measured in the area west of Camasobres. However, a full succession occurs in the area SW of Casavegas where a watershed separates the grounds of this village from those of Lores. The corresponding mountain ridge, running at right angles to the strike of the steeply dipping rocks, provides an ideal opportunity for measuring a complete section from the Maldrigo Limestone up to the Rosa María coals in the core of the Casavegas Syncline (text-fig. 1). Sandstone and limestone bands crossing over the ridge, form prominent features (Pl. 1; Pl. 2, fig. 1), and these have been recorded diagrammatically by van Ginkel (1960), who also identified fusulinid faunas from the limestones. Intervening mudstones are more patchily exposed but are always near enough to the surface to be trenched without difficulty. Coals are sometimes exposed by old diggings or marked by small tips, but trenching was necessary to expose the full succession of coals. A completely trenched, continuous exposure was studied by the present writers near the watershed on the Lores side. This is the area known as La Ojosa (text-fig. 1).

In order to provide an overlap with the section studied near Casavegas, the section was started at the horizon of the upper Casavegas coals. Identification of these coals is made easy by tracing the prominent sandstone ridge associated with these coals at Casavegas, and by checking the thickness of the sequence between the Casavegas Limestone (with «*Lonsdaleia*» *portlocki*) and the lower Casavegas coals.

Seam I of the latter is present as a coal seam at La Ojosa, but seam II is only represented by a seat-earth. Seams III and IV are both present. This part of the La Ojosa section was recently measured, after the log presented as text-fig. 7 had been drawn, and will thus only be described verbally.

Upper Casavegas coals (III-IV).

The La Ojosa section, starting at Casavegas seam III (0.25 m of carbonaceous shale followed by 0.60 m of coal), shows a prominent sandstone (30.40 m) with sporadic leached animal fragments near the roof of the seam and drifted plant remains (both comminuted and logs) becoming increasingly more common towards the top of the sandstone. Right at the top a seat-earth appears and it is clear that an initial transgression, after seam III, is followed by a general regressive tendency within the sandstone unit. Casavegas seam IV is found above the seat-earth at the top of the sandstone. This seam consists of two veins (0.15 m and 0.55 m respectively), separated by 0.50 m of carbonaceous shales and mudstone.

Littoral and marine deposits.

Ripple cross-laminated siltstones and sandstones above the Casavegas seam IV probably indicate transgression and a littoral environment, similar to that recorded above this coal seam in the Casavegas road section already described. An influx of comminuted plant remains at 2.85 m above the base of this transgressive sandstone, shows a tendency for temporary regression lasting through 1.80 m, after which leached animal fragments appear in a fine-grained, well sorted sandstone. This is followed by ripplemarked sandstone and siltstone, probably indicating a littoral environment. Animal fragments and comminuted plant debris are found at several levels of a total of 6.45 m sandstone, which then changes upwards into silty and very silty mudstones with shell remains at several intervals, brachiopods and bryozoa being recognized.

After 1.20 m a slightly silty, somewhat calcareous mudstone is reached. It is abundantly fossiliferous in 4.70 m, but the preservation of the fossils is poor due to fragmentation. This unit becomes increasingly fine-grained upwards. The next 0.80 m are extremely fossiliferous, with abundant brachiopods and lamellibranchs, but also gastropods, bryozoa, trilobites, crinoids and an occasional nautiloid. Dr. C. F. WINKLER PRINS (pers. comm.) identified the following brachiopods from this locality (2171):

Rhipidomella sp.
Isogramma sp. nov.
Neochonetes latesinuatus miaokouensis (CHAO).
Globosochonetes? sp.
Juresania sp.
Alexenia sp.
Karavankina sp.

Avonia (Quasiavonia) aff. *echidniformis* (CHAO).
Krotovia? aff. *curvirostris* (SCHELLWIEN).
Krotovia (Jakutella) cf. *sarytchevae* ABRAMOV.
«*Horridonia*» *incisa* (SCHELLWIEN).
Cancrinella sp.
Cleiothyridina cf. *pectiniformis* (SOWERBY).
Hustedia sp.
Zaissania sp.
Brachythyrina sp.
Martinia sp.
rhynchonellids.

This fauna may be tentatively assigned a Kasimovian age. It is certainly not older than late Myachkovian.

The horizon of loc. 2171 should be compared with that of the calcareous mudstone at some 9 metres above the highest Casavegas coal in the Casavegas road section (text-fig. 3). A slight increase in siltiness leads to 7.90 m of mainly silty and slightly silty mudstones which are followed by 1.20 m of thinly bedded, fine-grained sandstone with comminuted plant debris.

The subsequent 40.40 m show predominantly silty mudstones alternating with siltstones which are often ripple cross-laminated and which contain occasional comminuted plant debris. The sequence becomes generally more sandy, but with the same siltstone/mudstone alternations in the next 8.95 m. Coarsening upwards, a thick sandstone unit (13.70 m) with occasional siltstone and mudstone intercalations, shows frequent comminuted plant debris and some evidence of ripple marking near the base.

At the top of this regressive unit, a renewed transgression is marked by sparse leached animal remains in the sandstone and before another mudstone/siltstone alternation (3.75 m thick) is reached. The latter forms the lower part of a further regressive unit, leading from siltstone into sandstone (6.45 m) with indications of current bedding. Subsequent transgression leads through siltstone into slightly silty mudstone and calcareous mudstone of the quiet basin facies. Although shell remains are observed in this calcareous mudstone, no determinable elements could be found in the 3.75 m represented. Coarsening upwards, a long sequence of mudstone/siltstone alternations (14.90 m) passes into sandstone and siltstone (4.05 m), the upper part of which is taken up in another transgression marked by the presence of lamellibranchs, crinoids, etc. There follow silty mudstone (0.80 m) and slightly silty mudstone (4.50 m) which becomes slightly calcareous and which leads into calcareous mudstone (4.20 m) with abundant brachiopods, lamellibranchs, gastropods, trilobites, bryozoa, etc. Among the brachiopods Dr. C. F. WINKLER PRINS (pers. comm.) recognized the following (loc. 2167):

chonetids.
Avonia (Quasiavonia) cf. *echidniformis* (CHAO).
Kozlowskia sp.

Karavankina sp.
Brachythyrina sp.
Hustedia sp.

Slightly silty and silty mudstones in 14.20 m yielded abundant brachiopods, crinoids, lamellibranchs, bryozoa, etc. (loc. 2166). According to Dr. C. F. WINKLER PRINS (pers. comm.), the brachiopod fauna of this locality is similar to that mentioned above.

Slightly silty, calcareous mudstone (0.20 m) is then followed by silty mudstone with siltstone layers incorporated by bioturbation (1.55 m). This horizon is fossiliferous; containing bryozoa, crinoids, lamellibranchs and brachiopods. This leads into another long section of silty mudstones alternating with siltstones and fine-grained sandstones (46.65 m). The occasional presence of comminuted plant debris and ripple cross-lamination indicates temporary shallowing of the marine basin. Rare animal remains, mainly crinoidal, are also found. Coarsening upwards, the succession then shows an increasing amount of ripple cross-laminated siltstone, alternating with relatively little mudstone (6.90 m). Through ripplemarked sandstones and siltstones with subordinate mudstone (3.85 m), a prominent sandstone is reached with current bedded horizons, vertical burrows at one horizon and common plant remains (including stems) in the upper part (16.45 m). Animal debris also occurs at certain horizons but becomes more common in the subsequent 6.60 m of sandstone, which apparently represent renewed transgression.

Alternating siltstones and silty mudstones (2.35 m) then form a short coarsening upwards sequence with fine-grained sandstone (1.45 m) containing comminuted plants and animal debris. Slightly calcareous, silty mudstone (6.00 m) is subsequently followed by alternating silty mudstones and siltstones with occasional fine-grained sandstones (52.90 m), passing into slightly calcareous mudstone (4.45 m), silty mudstone with animal remains (3.30 m) and, finally, calcareous mudstone with limestone.

Lores Limestone.

At La Ojosa this limestone reaches a maximum thickness of 95 m, but it constitutes a lens which wedges into calcareous mudstone on both sides of the watershed (text-fig. 1). Limestone lenses at this horizon re-appear near Lores and both north and east-southeast of Areños. The large limestone lens at La Ojosa, between Casavegas and Lores (Pl. 1), has been named the Lores Limestone by VAN GINKEL (1960, 1965), who recorded a fusulinid fauna of late Upper Moscovian (Myachkovian) age (i. e. VAN GINKEL's *Fusulinella* Zone, subdivision B_3).

From the Lores Limestone upwards a fully measured section is recorded in text-fig. 7 (scale 1 : 1000), and a representative part of this section is also reproduced at 1 : 100 (text- fig. 8). Measurements quoted in the following pages refer to the figures in text-fig. 7, and are taken from the base of the limestone.

Q u i e t   b a s i n   a n d   c o a r s e n i n g   u p w a r d s   s e q u e n c e s.

The Lores Limestone is followed by a substantial sequence of mudstones, slightly silty and silty, with occasional sandstone partings sometimes containing comminuted plant debris. This succession, which becomes gradually more silty in the upper part, contains a more important sandstone unit at 235 m above the base of the Lores Limestone. It is thinly bedded and, together with an increase in the occurrence of comminuted plant debris, it may provide an indication of more shallow water, thus creating the impression of quiet marine basin sedimentation being followed by near shore deposits in a generally regressive unit.

Evidence of beach or estuarine deposits continues up to 255 m, with siltstones and sandstones showing ripple cross-laminations. Comminuted plant debris is common and in one horizon of silty mudstones it is accompanied by animal fragments, mainly crinoid ossicles.

A sudden deepening is marked by slightly silty mudstones, containing rare animal fragments (including possible ostracodes near the base) and even rarer plant debris (at 1.70 m above the base), which appear above the sandy deposits at 255 m. These mudstones are at the base of a coarsening upwards sequence, with micaceous silty mudstones and siltstones. The latter are succeeded by mudstones and siltstones with occasional bands of marine fossils, mainly represented by crinoid debris. Finely comminuted plant remains occur at one horizon.

Further upwards, at 273 m, calcareous mudstone bands with abundant fossil remains are found, crinoids and gastropods being recorded. The succession continues with generally silty mudstones, bluish grey in colour, and sometimes showing bioturbation. Comminuted plant debris comes in at 284 m, continuing up to 294 m, and vertical burrows are recorded in siltstones at 288 m and 291 m. At 295 m the grain size of the rock diminishes suddenly at the same time as comminuted plant debris is replaced by animal fragments (crinoids, lamellibranchs, etc.). Perhaps another deepening of the basin occurred at this level. Slightly silty mudstones at 296 m contain thin bands of bioturbated strata with occasional brachiopods and possible ostracodes. A siltstone at 298 m shows bands with abundant crinoid debris. Comminuted plant debris reappears at 300 m in a brief succession of coarsening upwards strata which also contain animal fragments, including lamellibranchs and crinoids. These units have all been generalized in the simplified section of text-fig. 7.

At 302.50 m a new cycle of coarsening upwards strata commences with silty mudstone, containing lamellibranchs, crinoids, brachiopods, etc., and continues with 4.20 m of slightly silty mudstone, bioturbated at certain levels and passing upwards into very silty, micaceous mudstone with uncommon plant debris at one horizon. A succession with predominant siltstones follows, with some very silty mudstone and three thin sandstone bands. Occasional comminuted plant debris is recorded, and some of the siltstones show ripple cross-laminations. This succession passes upwards into thinly

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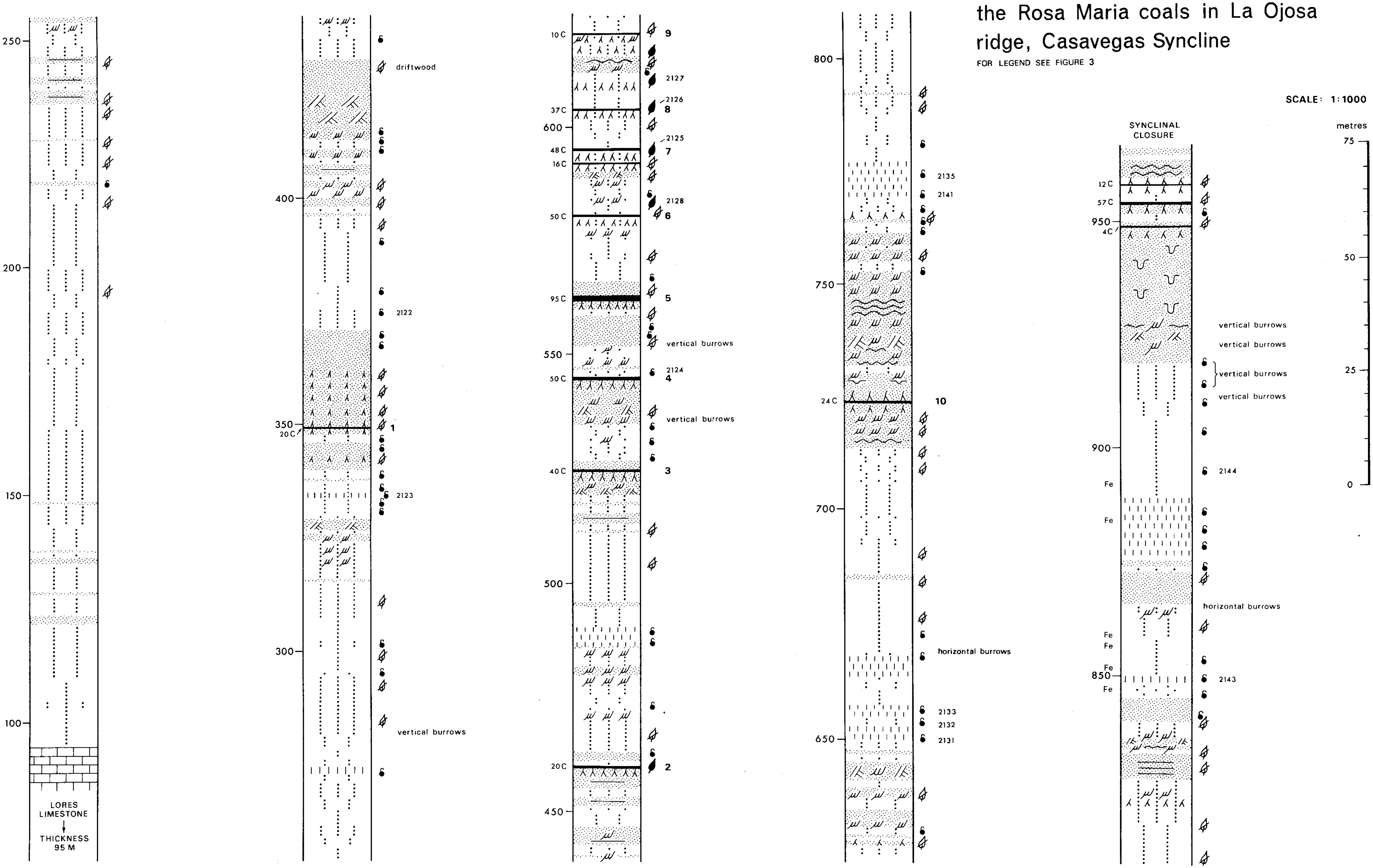
Text-fig. 7.—Simplified section (scale 1:1,000) of strata measured in the La Ojosa ridge. Ojosa Formation. Areños seams numbered 1 to 10. Rosa María coals at 950 m.

Section from the Lores Limestone to the Rosa Maria coals in La Ojosa ridge, Casavegas Syncline

FOR LEGEND SEE FIGURE 3



bedded, fine-grained sandstone with ripple cross-lamination in the basal 20 cm. After an interval of silty mudstone and siltstone, two bands of current bedded, fine-grained sandstone are reached. These may well indicate a marine deltaic facies at the top of a regressive sequence. Further sandstones and siltstones without apparent sedimentary structures continue this succession, which is interrupted at 330 m by a silty mudstone with indeterminate animal remains. This is succeeded by calcareous mudstones with an important fauna of lamellibranchs, gastropods, brachiopods, trilobites, crinoids, bryozoa, ostracodes (loc. 2123). Among the brachiopods Dr. C. F. Winkler Prins recognized the following elements (pers. comm.):

marginiferid
Cancrinella sp.
Globosochonetes sp.
Choristites sp.
Zaissania sp.

These rocks evidently mark the beginning of a new transgression, thus terminating the regressive sequence underneath. Silty mudstones with animal fragments follow in succession, and these contain occasional siltstone and sandstone bands in the upper part. Abundant crinoids and lamellibranchs have been recorded from a thin siltstone in this part of the succession. Further upwards, cream coloured, massively bedded, well washed sandstones are found, at the top of which occurs the first seat-earth of the La Ojosa section. This marks the first occasion at which a regressive sequence in the section above the Lores Limestone shows actual emergence from an aqueous environment.

Areños coals.

This seat-earth is the first of a sequence of non-marine strata, including coals. These have been worked most extensively in the vicinity of Areños. A thin siltstone (0.20 m) with comminuted plant fragments overlies the seat-earth which is a simple root bed without coal. There follow both massive and thinly bedded sandstones, with finely comminuted plant remains and animal fragments (crinoids and lamellibranchs) at certain intervals. A subsequent development of silty mudstones and siltstones with crinoids, lamellibranchs and gastropods shows a continuing marine environment. This changes upwards into non-marine with a sandstone, 0.60 m thick, containing abundant Stigmarian rootlets in the top 0.10 m. This seat-earth is overlain by a thin, dirty coal (0.06 m) with a probably fluviatile sandstone forming its roof. The latter contains drifted fragments of coal and fairly large, drifted plant remains. The upper 0.05 m of this sandstone show a few rootlets and represent the seat-earth of another dirty coal (0.11 m). This is overlain by sandstone with a siltstone parting. The top 0.08 m of this sandstone also contains abundant rootlets and constitutes the seat-earth of a coal smut, 0.04 m thick. The three small veinlets are taken together as Areños coal 1, even though this horizon seems to be generally non-workable, and has been little explored in the area of the Casavegas Syncline.

A continuing non-marine facies is represented by sandstone with several seat-earths, accompanied in the lower part of the sandstone by carbonaceous silty shales and siltstones. Drifted plant remains are found throughout the sandstone, though in varying quantity. The root beds become gradually less common in the upper part of the sandstone and this is accompanied by the gradual disappearance of drifted plant remains. A definite return to marine conditions is marked by the presence of crinoids and further, indeterminate, animal remains in the top part of the sandstone. It thus seems that a regressive sequence with recurrent levels of seat-earth (and coal) was followed by transgression, which probably reworked the non-marine sands. The predominantly massive character of the marine sandstone, the virtual absence of ripplemarks (only 0.20 m out of 6.45 m show ripples), and the presence of crinoids all seem to point at a relatively sudden transgression with an apparent lack of beach deposits.

A change to siltstone marks the diminishing supply of coarse-grained material, this being further emphasized by a sequence of slightly silty mudstones following in succession. Near the top of the siltstone a fossil locality (2122) has yielded brachiopods, crinoids, lamellibranchs, gastropods, etc. Among the brachiopods Dr. C. F. WINKLER PRINS (pers. comm.) recognized:

Juresania subpunctata (NIKITIN).
Isogramma aff. *davidsoni* (BARROIS).
strophomenid.

The presence of *J. subpunctata* seems to point to a Kasimovian rather than a Myachkovian age. More marine fossils continue to be found until an horizon of micaceous siltstone is reached, where comminuted plant debris is encountered instead. Comminuted plants then occur in an increasingly more sandy succession showing frequent ripple cross-laminations and, eventually, current bedding; thus demonstrating the progressive shallowing associated with the regressive sequences characterizing the La Ojosa section. The top of this sequence, at 425 m, is marked by a one metre thick massive sandstone which may or may not be non-marine. It contains drifted tree trunks, up to 2 m in length. This is succeeded by 5.35 m of massively bedded, light coloured sandstone with drifted plant debris. Quite possibly, this should be interpreted as the first deposit formed after renewed transgression, reworking sands deposited previously. Very silty, bioturbated mudstones and silty mudstones follow in a succession which leads on to siltstones with ripple cross-laminations, and to thinly bedded sandstones. The top of this succession is formed by 1.80 m of fine-grained, well washed quartz sandstone at 445 m.

An abrupt contact with slightly silty mudstone probably marks another transgression and the beginning of a regressive unit which gradually becomes coarser upwards, into thinly bedded sandstones terminated by a seat-earth and a coal of 0.20 m

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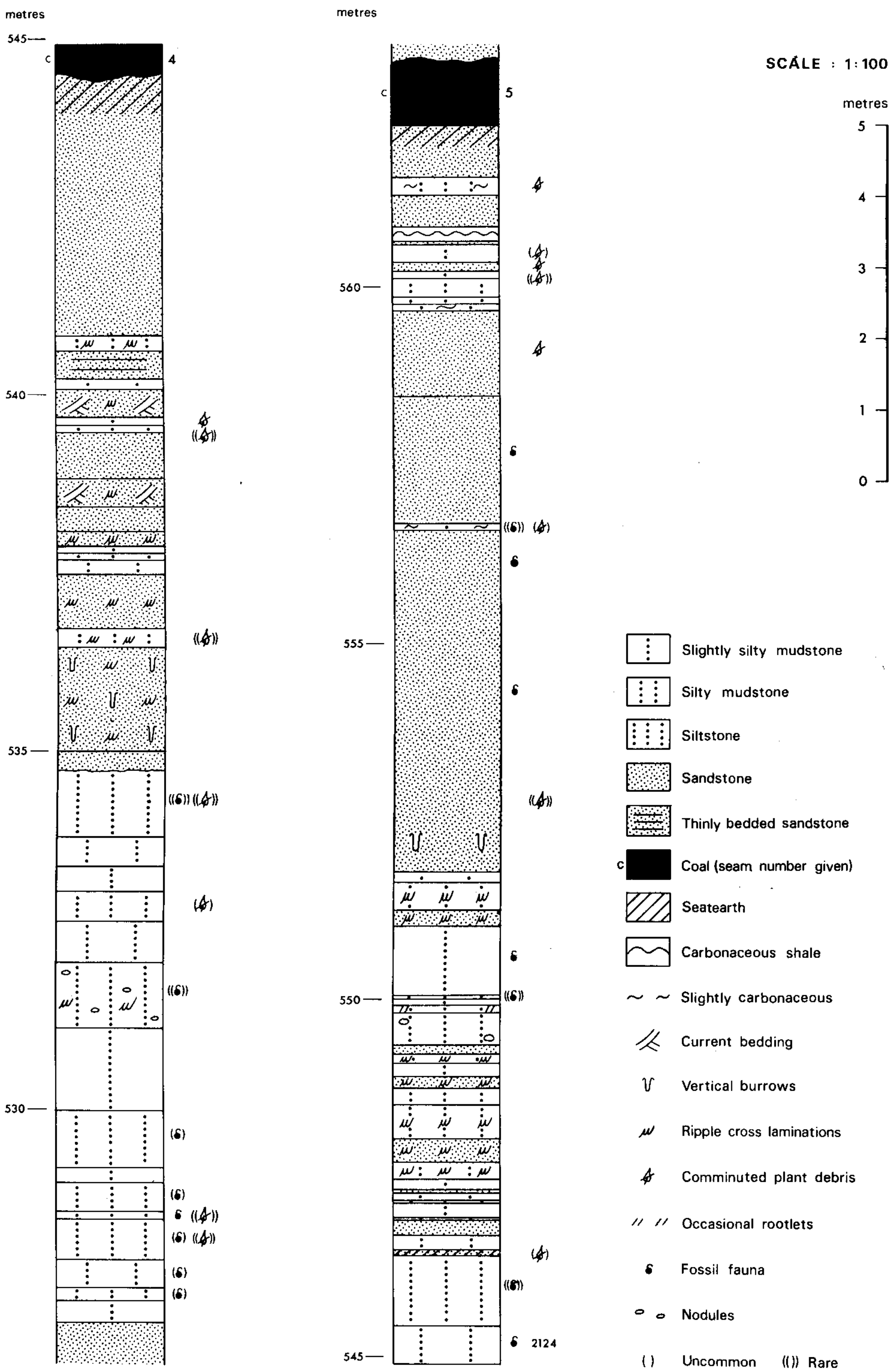
Text-fig. 8.—Detailed section (scale 1:100) of two representative coarsening upwards sequences in the La Ojosa section. Ojosa Formation.

Regressive sequences in La Ojosa section



thickness. This coal is marked number 2 in the sequence of Areños seams and is probably the lower coal referred to by NEDERLOF & DE SITTER (1957), who discussed the workability of the Areños coals.

Above seam 2 a strongly weathered clay is succeeded by slightly silty grey shale with *Cordaites*, *Calamites* and indeterminate plant fragments. A further seat-earth is followed by siltstone and fine-grained, massively bedded sandstone (bedding interval *ca.* 15 cm). This is succeeded by a slightly ferruginous, medium-grained sandstone with marine fossils (lamellibranchs, crinoids, etc.), representing the basal, transgressive, deposit of another regressive unit.

This unit shows silty mudstones, siltstones and very silty mudstones (the latter mainly consisting of alternating siltstones and silty mudstones mixed up by bioturbation), with occasional rare plant debris and some marine fossils at intervals. Some of the siltstones show ripple cross-laminations. Further up the sequence ripple cross-laminated siltstones and thinly bedded sandstones become rather common.

This regressive development is terminated by a somewhat calcareous sandstone, slightly ferruginous and with crinoid debris, which is followed by calcareous mudstone. Siltiness increases upwards and comminuted plant debris is found throughout the main part of this regressive sequence which ends with current bedded and ripple cross-laminated sandstone containing a massive seat-earth followed by coal. This coal, 0.40 m thick, is marked as seam 3.

This coal is overlain by 2.90 m of light cream coloured sandstone, well washed and massive to massively bedded, which has an irregular base but which shows no clear evidence of channelling.

The next regressive unit (text-fig. 8) commences with slightly silty mudstone followed by siltstones with shell fragments, and these are succeeded by silty mudstone with crinoid debris and other leached indeterminate animal remains. Minor movements may be marked by alternating silty mudstones and siltstones, one of the latter containing ripple cross-laminations. The upper part of this rhythmic unit consists of sandstone with siltstone and silty mudstone partings. In the lower part of this sandstone vertical burrows and ripple cross-laminations are observed. Halfway up the sandstone a current bedded interval occurs before another layer with ripple cross-laminations is reached. The upper part of the sandstone is massive, grey, internally laminated, fine-grained, with a bedding interval of 5-45 cm. The top of the sandstone is penetrated by Stigmarian rootlets forming the seat-earth of seam 4, which is 40-53 cm thick in this section.

Seam 4 suffered a rapid transgression, since it is overlain by 0.55 m of highly fossiliferous silty mudstone containing poorly preserved lamellibranchs, gastropods, crinoids, etc. (loc. 2124). This is followed by very silty mudstones with indeterminate shell debris. A thin root bed above this horizon marks another temporary regression, after which probably marine silty shales, sandstones and siltstones with ripple cross-laminations occur in a regressive unit which is terminated by slightly silty mudstone, 1.05 m thick. The latter contains fairly common remains of a leached fauna of lamellibranchs, gastropods, etc. This horizon lies at the base of a regressive unit with ripple cross-laminated sandstone and siltstone leading upwards into a massively bedded, well washed sandstone (bedding interval 20-40 cm). Burrows are present in a 0.70 m thick interval beginning at 0.20 m above the base of the sandstone and rare drifted, comminuted plant remains occur in the 0.90 m above the burrowed interval. Somewhat higher in the sandstone leached animal remains are found, and about halfway, just below a thin mudstone parting with highly comminuted plant debris and fragments of lamellibranch shells, markings of *Zoophycos* are recorded. Leached shell remains still occur above the mudstone parting, but higher in the same sandstone sequence only comminuted plant remains are encountered. Mudstones and siltstones with comminuted plant debris and some carbonaceous shale layers follow in a succession which ends with sandstone containing a seat-earth at the top. This seat-earth belongs to seam 5.

Seam 5, with a thickness of 0.95 m in the La Ojosa section, is overlain by 2.65 m of massive sandstone with an irregular base and containing drifted plant remains. This should probably be interpreted as a non-marine channel sand.

After 0.10 m of silty mudstone, 0.45 m of well washed sandstone with drifted plant remains, and 0.35 m of siltstone with drifted plants, continue the probably fluviatile facies.

A marine transgression is indicated by a silty mudstone containing lamellibranchs, which lies at the base of a sequence of primarily mudstone but which also comprises siltstones with drifted plant remains. Sandstone partings and siltstones with ripple cross-laminations appear higher in this succession which is terminated by another marine band with lamellibranchs and other, indeterminate, marine fossils, at 577.50 m. This is followed in quick succession by thin sandstone and siltstone bands, carbonaceous, silty and slightly silty shales, a seat-earth and coal seam 6 (0.50 m thick).

This coal is overlain by a sequence of silty mudstones, slightly silty mudstones and siltstones with drifted plant remains, and a single layer of silty mudstone with identifiable land plants (loc. 2128 — R. H. W. *det.*):

Neuropteris ovata var. *grand'euryi*? WAGNER.
Linopteris obliqua var. *bunburyi* BELL.
Alethopteris missouriensis D. WHITE.
Sphenopteris sp.
Sphenophyllum emarginatum BRONGNIART.

At 585.30 m a slightly silty mudstone with lamellibranchs, brachiopods and crinoids inaugurates a brief marine interval at the base of a regressive sequence, which passes through silty mudstone with a sparse marine fauna (lamellibranchs), and ripplemarked siltstone into a current bedded sandstone. This is followed by another coarsening upwards sequence which culminates in several thin coals. These are succeeded by alternating seat-earths and roof shales, one of which contains *Alethopteris missouriensis* D. WHITE and *Pecopteris* sp. (loc. 2125 — R. H. W. *det.*). The last seat-earth of this complex forms the underclay of seam 7 which is 0.48 m thick. Its roof shales are plant-bearing and although the next sequence is again coarsening upwards, there are no clearly marine strata involved in the interval leading to seam 8.

The roof of this rather thin seam (0.37 m) consists of silty mudstone which has yielded a single pinnule of *Linopteris palentina* WAGNER, in a macerated condition (loc. 2126). Drifted plant debris occurs throughout the next 5 metres, after which a seat-earth is reached. Drifted plant remains and occasional identifiable plants have also been found 2 metres above this seat-earth (loc. 2127 — R. H. W. *det.)*:

Linopteris palentina WAGNER.
Alethopteris missouriensis D. WHITE.
Sphenophyllum emarginatum BRONGNIART.

The only sign of marine fossils has been found at the base of a sandstone above this interval, where poorly preserved lamellibranchs occur together with drifted plant remains. Occasional rootlets are found not too far above this marine band which thus represents a transitory episode. Massively and thinly bedded intervals alternate in this sandstone which also contains ripple cross-laminations and ripplemarks. Further alternating silty mudstones and siltstones contain a single seat-earth as well as relatively abundant drifted plant remains. At 0.40 m below seam 9 a few identifiable plants were found (loc. 2130 — R. H. W. *det.*):

Linopteris obliqua (BUNBURY) ZEILLER.
Sphenophyllum emarginatum BRONGNIART.

Seam 9, the last coal in the closely spaced seams forming the bulk of the Areños coals, is only 0.10 m thick (i. e. excluding the carbonaceous shales accompanying this seam).

The sequence of slightly silty mudstones, silty mudstones and siltstones with occasional drifted plant remains (comminuted), which follows upon seam 9, may be marine. It shows the usual coarsening upwards leading into sandstone and, eventually, seat-earth. Five additional coarsening upwards sequences, with sandstones showing ripple cross-laminations and current bedding, are found before a clearly marine succession of mudstones and calcareous mudstones, with faunal remains, is encountered. These comprise lamellibranchs, gastropods, brachiopods, crinoids, corals, trilobites, ostracodes. Among the brachiopods Dr. C. F. WINKLER PRINS (pers. comm.) identified the following (loc. 2131):

Karavankina sp.
linoproductid.
chonetid.
rhynchonellid.

The marine mudstones from here-on show a generally increasing number of coarser intervals, siltstones and very silty mudstones, in upward succession. At the same time, comminuted plant debris increases and faunal bands disappear. At 711 m the comminuted plant remains become abundant and at 713.50 m a thick sandstone, with relatively coarse drifted plant fragments at its base, and ripplemarks and ripple cross-laminations higher up, marks the top of a regressive unit which culminates in seat-earth and coal. The latter is counted as seam 10 (0.24 m thick) and is the last of the Areños coals.

By counting ten seams for the Areños coals the present authors are incorporating additional seams with the group of coals that has been worked in the area of Areños. Seams 1, 2 and 10 are separated by an appreciable thickness of strata from the main coal-bearing sequence (seams 3 to 9), which has been recorded as the «grupo de Areños» by NEDERLOF & DE SITTER (1957, p. 20). Only the latter seams have been worked by the small coal mines in the neighbourhood, and seams 1, 2 and 10 have generally not even been explored. Most of the small mines that worked the Areños coals (3-9) have been abandoned (e. g. Mina Aurora, Mina Vasco-Cántabra — text-fig. 1), but some are still in operation (Mina Eugenia/Pilarica, Mina Cardil). Apart from the Mina Aurora, which worked a complex of seams, the exploitation in these small mines centred almost exclusively on one seam in the upper part of the principal coal-bearing sequence. Due to tectonic squeezing and small scale strike faulting, different seams may be workable in different parts of the area, and it appears unlikely that the same seam has been worked in the different coal mines. The numbering of the seams is also different in the various mines and an independent numbering, based on a full sequence as explored in the present investigation, is in order.

From the spoil tips which dot the crop of the Areños coals, several collections of fossil plants were made. The most important collection was obtained from the tip of the Mina Aurora on the northern side of the Río Areños (loc. 1403 - R. H. W. *det.*):

Neuropteris scheuchzeri HOFFMANN.
Linopteris palentina WAGNER.
Callipteridium (Praecallipteridium) jongmansi (P. BERTRAND) WAGNER.
Alethopteris ambigua LESQUEREUX.
Alethopteris lesquereuxi WAGNER.
Alethopteris grandinioides var. *subzeilleri* WAGNER.
Alethopteris palentina WAGNER.
Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.
Pseudomariopteris ribeyroni (ZEILLER) DANZÉ-CORSIN.
Sphenopteris sp.
Pecopteris melendezi WAGNER.
Pecopteris unita BRONGNIART.
Pecopteris cf. *arborescens* (VON SCHLOTHEIM) BRONGNIART.
Pecopteris sp.
Sphenophyllum emarginatum BRONGNIART.

From the tip of the Mina Vasco-Cántabra the following fossils were collected (loc. 1913 — R. H. W. *det.*):

Callipteridium (Praecallipteridium) armasi (ZEILLER) WAGNER.
Alethopteris grandinioides var. *subzeilleri* WAGNER.

Alethopteris lesquereuxi WAGNER.
Sphenopteris sp. div. (2 species).
Pecopteris unita BRONGNIART.
Pecopteris arborescens (VON SCHLOTHEIM) BRONGNIART.
Sphenophyllum emarginatum BRONGNIART.

The tip of the Mina Eugenia yielded (loc. 2260 — R. H. W. *det.*):

Neuropteris scheuchzeri HOFFMANN.
Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.

These floras are not significantly different from those collected at the horizon of the upper Casavegas coals, but the presence of *Pecopteris melendezi* is an argument in favour of early Stephanian rather than late Westphalian D. The Areños coals are therefore regarded as lower Cantabrian in age.

Seam 10, the highest of the Areños coals in the La Ojosa section, is overlain by another sandstone, massively bedded to massive, leading up to a root bed which is overlain in turn by 1.10 m of massive sandstone. The whole of this sandstone complex, associated with coal and root beds, is well washed, medium and fine-grained, light yellow and light grey in colour. At 1.10 m above the second root bed a thin band of sandstone with leached crinoids and lamellibranchs marks a marine transgression. Channel sandstones, again well washed, follow in a succession which passes into sandstones and siltstones with ripple cross-laminations and ripplemarks. After a relatively short interval of current bedded sandstone, a long succession of ripple cross-laminated and ripplemarked sandstone is encountered. Crinoid debris is found at two horizons in the upper part of this succession which appears to be entirely shallow marine in facies, from the faunal horizon above the coal and root beds onwards.

An interval of silty mudstone appears at 758 m, but a rather quick return to ripple cross-laminated sandstone and the persistence of comminuted plant remains throughout the mudstone, as well as the sandstone, probably indicate a continuing littoral facies. At 761.30 m, however, comminuted plant debris gives way to marine fauna, indicating a transgressive movement at the base of a regressive sequence which ends with a root bed at 765 m. This root bed is correlated with a thin coal in exposures near Urbaneja, in the riverbed of the Río Areños (text-fig. 1), and the numbering of the Areños coals may therefore go up to 11.

Coarsening upwards sequences without coal.

Another transgression is marked above the root bed («seam 11») in the La Ojosa section by slightly silty mudstones with faunal remains as well as comminuted plant debris, and which pass into silty mudstones with animal remains and occasional bands of siltstone with ripple cross-laminations. A quiet marine basin, with relatively little sedimentation, is indicated by the following long interval of calcareous mudstone and slightly silty mudstone leading upwards into silty mudstone. The calcareous mudstone contains abundant marine fossils, including brachiopods, lamellibranchs, crinoids, bryozoa, gastropods, ostracodes and corals. The well preserved brachiopods (loc. 2135) include the following elements (C. F. WINKLER PRINS, pers. comm.):

cf. *Avonia (Quasiavonia) echidniformis* (CHAO).
Karavankina sp.
Juresania subpunctata (NIKITIN).
Alexenia sp. ex gr. *A. reticulata* IVANOVA.
Kozlowskia sp.
Cancrinella sp.
chonetid.
Zaissania sp.
Phricodothyris sp.
rhynchonellid.

The long mudstone succession changes to very silty mudstone and siltstone at 818.30 m. At a somewhat higher level comminuted plant debris becomes common again, and ripplemarked and ripple cross-laminated siltstones appear. This regressive sequence ends with current bedded sandstone at 835 m, after which ripple cross-laminated siltstones indicate the beginning of a transgression which is more clearly marked at 841.50 m by a slightly silty mudstone with marine fossils. There follows a massive sandstone, presumably marine, which is succeeded by silty mudstones, sandstone and siltstones, one of which shows ripple cross-laminations. The more sandy, upper part of this succession is somewhat ferruginous and contains sparse marine faunas.

At 848 m another coarsening upwards sequence commences with calcareous, slightly silty mudstones with abundant animal remains comprising lamellibranchs, crinoids, brachiopods, bryozoa and fusulinid foraminifera (loc. 2143). According to WINKLER PRINS (pers. comm.) *Juresania* sp. and a linoproductid occur among the brachiopods in this locality. The long sequence of mudstones is terminated by siltstones with ripple cross-laminations and horizontal burrows, and these are succeeded by massive sandstones alternating with occasional siltstones in the upper part. The entire succession is marine.

At 875 m a new succession of calcareous mudstones, with abundant though poorly preserved faunas, represents the beginning of yet another regressive sequence which passes through slightly silty and silty mudstones with occasional faunas into a succession of siltstones and very silty mudstones with faunal remains and vertical burrows. This coarsening upwards sequence leads into a sandstone, still containing some marine fauna in the basal part, and showing ripple cross-laminations, vertical burrows and, at one horizon, current bedding. Beyond the first 9 m, containing these fossils and sedimentary structures, a massively bedded, well washed, quartzitic sandstone occurs. It shows frequent channelling and may be regarded as fluviatile or estuarine in origin. This part of the sandstone is *ca.* 20 m thick and accompanies a coal-bearing sequence.

Rosa María coals.

The sandstone is overlain by a seat-earth with carbonaceous shale and a very thin coal smut (0.04 m), with drifted plant remains in roof shales. Another sandstone, containing a few carbonaceous streaks at the top, is followed by slightly silty mudstones which are at the base of a short coarsening upwards sequence. The transgressive character of the basal deposits of this regressive sequence is shown by the presence of poorly preserved shell remains in the silty mudstone and in the overlying sandstone. The latter also contains a few rootlets heralding a seat-earth and coal that follow. This is the Rosa María coal seam (0.57 m) which is followed by another coal smut (0.12 m) after 4 metres of non-marine mudstone and a few thin sandstones, all of which contain abundant comminuted plant remains. These two coals were recorded as the Rosa María coal group by VAN GINKEL (1960). The thin rider seam is overlain by slightly silty mudstone followed by thinly bedded and ripplemarked sandstone, the total thickness of which could not be ascertained in the locality investigated (which lies in the core of the Casavegas Syncline).

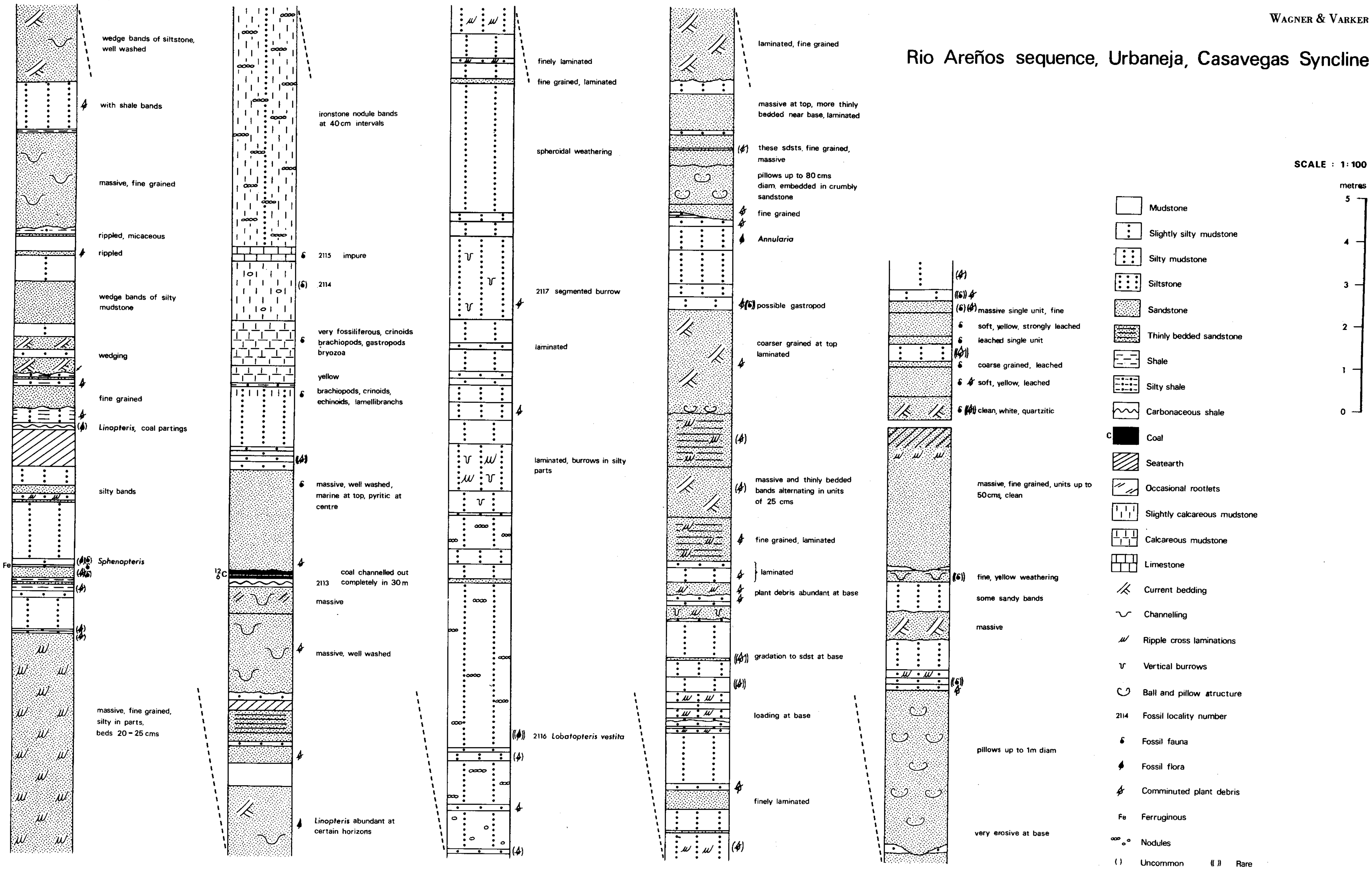
The Rosa María coals have been the subject of exploration and small scale workings in the Rosa María coal mine in the mountains west of Areños. The same coals, which can be easily traced in the field since they are accompanied by the massive Rosa María Sandstone (see above), have also been explored in diggings north of Urbaneja, where the following plant fossils were found in an old tip (loc. 2150 — R. H. W. *det.*):

Alethopteris cf. *lesquereuxi* WAGNER.
Mariopteris sp.
Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.
Sphenopteris cf. *mendes-correae* TEIXEIRA.
Pecopteris cf. *unita* BRONGNIART.
Pecopteris cf. *arborescens* (VON SCHLOTHEIM) BRONGNIART.
Sphenophyllum emarginatum BRONGNIART.

Río Areños section and its continuation at Urbaneja.

In the eastern flank of the Casavegas Syncline, continuing southwards along the crop of the Rosa María coals and sandstone, the top part of the sequence measured in the La Ojosa section is repeated and continued upwards by a well exposed succession in the Areños river north of Urbaneja (text-fig. 1), which has been completed by trenching across the hillside. The naturally exposed part of this section is reproduced at scale 1 : 100 by text-fig. 9. It has also been studied by H. G. READING (1970, text-fig. 3, section 5), who described its sedimentological detail. The top part of the

Text-fig. 9.—Detailed section (scale 1:100) of strata belonging to the upper part of the Areños coal horizon (containing seams 10 and 11), as exposed opposite the Mina Aurora in the bed and bank of the Areños river.


Rio Areños sequence, Urbaneja, Casavegas Syncline
wedge bands of siltstone, well washed
with shale bands
massive, fine grained
rippled, micaceous
rippled
wedge bands of silty mudstone
wedging
fine grained
Linopteris, coal partings
silty bands
Fe
Sphenopteris
massive, fine grained, silty in parts, beds 20 - 25 cms
ironstone nodule bands at 40 cm intervals
2115 impure
2114
very fossiliferous, crinoids brachiopods, gastropods bryozoa
yellow
brachiopods, crinoids, echinoids, lamellibranchs
massive, well washed, marine at top, pyritic at centre
C
coal channelled out completely in 30 m
2113
massive
massive, well washed
Linopteris abundant at certain horizons
finely laminated
fine grained, laminated
spheroidal weathering
2117 segmented burrow
laminated
laminated, burrows in silty parts
2116 Lobatopteris vestita
laminated, fine grained
massive at top, more thinly bedded near base, laminated
these sdsts, fine grained, massive
pillows up to 80 cms diam, embedded in crumbly sandstone
fine grained
Annularia
possible gastropod
coarser grained at top laminated
massive and thinly bedded bands alternating in units of 25 cms
fine grained, laminated
laminated
plant debris abundant at base
gradation to sdst at base
loading at base
finely laminated
massive single unit, fine
soft, yellow, strongly leached
leached single unit
coarse grained, leached
soft, yellow, leached
clean, white, quartzitic
massive, fine grained, units up to 50cms, clean
fine, yellow weathering
some sandy bands
massive
pillows up to 1m diam
very erosive at base
SCALE : 1:100
metres
5
4
3
2
1
0
Mudstone
Slightly silty mudstone
Silty mudstone
Siltstone
Sandstone
Thinly bedded sandstone
Shale
Silty shale
Carbonaceous shale
C
Coal
Seatearth
Occasional rootlets
Slightly calcareous mudstone
Calcareous mudstone
Limestone
Current bedding
Channelling
Ripple cross laminations
Vertical burrows
Ball and pillow structure
2114 Fossil locality number
Fossil fauna
Fossil flora
Comminuted plant debris
Fe Ferruginous
Nodules
( ) Uncommon
(( )) Rare

section, exposed by trenching, is fairly monotonous and is here only described verbally. It terminates in the synclinal core (text-fig. 1) with a slide limestone consisting of broken fragments of limestone in a mudstone matrix (compare text-fig. 11).

Areños coals 10 and 11.

The measured section commences, somewhat arbitrarily, at a well exposed sandstone which crosses the bed of the Río Areños opposite the abandoned Mina Aurora. It shows ripplemarks and ripple cross-laminations in a rather massively bedded rock (bedding interval 20-25 cm), and probably represents a beach or estuarine sand. This sandstone is followed by silty mudstones and shales with comminuted plant remains. A following sandstone and its immediately overlying mudstones contain faunal remains. Subsequent silty mudstones, with sandstone and siltstone partings showing ripple cross-laminations, lead up to a root bed associated with carbonaceous shales and thin leaves of coal. This horizon probably correlates with seam 10 of the Areños coals in the La Ojosa section. It is followed by silty mudstones with drifted plant remains, representing the roof shales of this poorly developed seam. These shales have been channelled into by a massive sandstone. Subsequent mudstones (generally silty or slightly silty) alternate with current bedded and wedge bedded sandstones as well as thin partings showing ripplemarks. A more substantial sandstone, higher in the succession, shows channelling, and the general facies appears to be non-marine. A thin shale separates this channel sandstone from siltstones with drifted plant remains, and these are succeeded by a sandstone with current bedding and channel bases. A dark blue mudstone separates the latter from another sandstone, partly thinly bedded, and leading up into a root bed. Overlying siltstones are channelled into by a further, non-marine sandstone with channel bases and showing the presence of driftwood, and which contains sparse rootlets in the top part. These represent the seat-earth of carbonaceous shales and a thin coal, 0.18 m thick in the locality measured. This coal probably equates to a root bed at the top of the sandy development at 765 m in the La Ojosa section (compare text-fig. 7), and may be numbered seam 11 of the Areños coals. It is overlain by a channel sandstone which cuts out the coal completely in a distance of 30 m along the strike northwards from the locality studied. This apparently non-marine channel sandstone, containing abundant driftwood in the basal part, changes upwards into a massive marine sandstone with pyritized marine lamellibranchs at 1.50 m from its base. At its top ripplemarks are observed, before this sandstone passes gradually into siltstone which may be regarded as a beach deposit. Reading (1970) mentioned this sandstone as an example of gradual transgression.

Marine basin.

The siltstone above the transgressive sandstone in the Río Areños section passes upwards, in a continuing transgressive sequence, through silty mudstone into calcareous mudstone and marl with abundant marine fossils, including lamellibranchs, gastropods, crinoids, spiriferid brachiopods, fenestellid bryozoa, etc. A calcareous mudstone with sideritic nodules separates this marl from a dirty, fossiliferous limestone which is succeeded in turn by calcareous mudstone with sideritic nodules. A silty mudstone with sideritic ironstone bands follows in a succession which contains a progressively increasing number of siltstone horizons, the latter showing evidence of ripple cross-laminations and vertical burrows. Conditions thus became progressively more shallow marine. A single, drifted plant fragment, belonging to *Lobatopteris vestita* (LESQUEREUX) (loc. 2116), was collected 16 m above the thin coal seam lower in the section. Drifted plant remains occur sparingly in this sequence of alternating silty mudstones and siltstones. At some horizons a very rapid alternation is observed, and at 26 m above the coal there is some flaking of mudstones which have become partially incorporated in siltstone layers and which thus appear to indicate a certain amount of sliding of sediment along the sea floor. The fine siltstones become gradually more common upwards, and at 38.50 m above the coal a burrowed, ripple cross-laminated sandstone inaugurates a succession of alternating sandstones and siltstones passing into a 5.70 m thick sandstone complex. This consists of thinly bedded, ripple cross-laminated sandstone followed by current bedded and ripple cross-laminated sandstone, and these are succeeded by more ripple cross-laminated sandstone which is overlain by an horizon of ball and pillow structures showing clear signs of loading. This passes into a more substantial current bedded unit.

After 2.30 m of silty and very silty mudstones another sandstone unit with large ball and pillow structures is encountered. This unit wedges strongly and disappears in 20 m along the strike. The load balls are up to 0.80 m diameter and are found embedded in a crumbly, fine-grained, dirty sandstone (almost a very silty mudstone) forming layers around the balls (Pl. 2, fig. 2). This horizon is followed by bedded sandstone with siltstone partings. Throughout 0.25 m, commencing from 1 m above the ball and pillow horizon, the presence of numerous horizontal trails is noted in an exposure near the riverbed, and a little south of the section measured. After a blue, micaceous, very silty mudstone, a fine-grained, current bedded sandstone is reached. This is separated by a thin siltstone from a third ball and pillow horizon, which appears to have an erosive base cutting as much as 0.20 m down into the earlier deposit. Several balls and pillows are found, each of which appears to cut down into previous deposits. Individual balls reach up to 1 m in diameter. Much of the sandstone between the balls and pillows is thinly bedded and micaceous.

Siltstones with drifted plant debris follow in a succession which also comprises siltstones with indeterminate animal remains (marine) and, at one horizon, ripple cross-laminations. A compact, very sandy mudstone is then followed by sandstone, channelling at the base, and showing current bedding. A siltstone with some sandstone bands is found subsequently in a succession which is dominated by channelling sandstones, the first one of which contains indeterminate animal debris. The second sandstone, 3.30 m thick, is massively bedded (units up to 0.50 m thick), with some ripple cross-laminations. It is terminated by 0.45 m of seat-earth, with abundant rootlets in a light coloured quartzitic sandstone. Apparently, the facies changed from near shore marine to continental in a regressive sequence within this sandstone.

After a 0.15 m gap, which could not be exposed by trenching in the section measured, a clean quartzitic and current bedded sandstone with crinoid debris and rare plant remains is encountered. This sandstone grades upwards into a porous, probably calcareous sandstone with leached animal remains, particularly crinoids. After a siltstone with rare drifted plant fragments, another soft, yellow, strongly leached sandstone with abundant animal remains is reached. The majority of the fossils in this deposit are represented by iron stained cavities. Further upwards the animal remains are accompanied by drifted plant debris.

The transgressive tendency evidenced by these fossil bearing sandstones is maintained by a fairly long sequence of silty and slightly silty mudstones with siltstones and thin sandstone partings containing fairly abundant animal remains and less common plant debris. Crinoid fragments are most commonly encountered, but lamellibranchs and bryozoa are also found. The section drawn in text-fig. 9 ends near the base of the mudstone sequence, but the measured section continues and will be verbally described below.

The quiet marine basin facies is temporarily interrupted by a ripple cross-laminated sandstone, which is succeeded by siltstone and silty mudstone. Subsequently, a 6.70 m thick sandstone occurs with a strongly erosive base, which channels down to 0.50 m into the preceding mudstone. Load casting occurs at the base of this sandstone, which also shows the presence of carbonized tree trunks. Further evidence of channelling is found throughout this sandstone, which is light coloured and quartzitic. It seems likely that it represents a shallowing of the sea and that the channelling took place in an estuarine environment, succeeding the quiet marine basin facies of the earlier deposits. Silty mudstones and siltstones, with rather frequently occurring animal remains and drifted, comminuted plant debris, show a return to the marine basin facies which is further continued by calcareous, yellow weathering mudstone, with lamellibranchs, bryozoa, brachiopods, crinoids, etc.

This horizon is followed in a regressive sequence by mudstones with various degrees of siltiness and containing relatively rare animal remains as well as drifted plant fragments, and by a thick sandstone which shows channelling and current bedding. This is a clean, well washed, quartzitic sandstone, with small amounts of comminuted plant debris at restricted horizons and some leached shell remains at intervals. Before emergence could take place, another transgression followed, as indicated by indeterminate marine fossils, occurring together with drifted plant remains in a sandy succession which passes rapidly into calcareous, slightly silty mudstone. After an interval of marine siltstone, similar quiet marine basin deposits follow before the Rosa María Sandstone is reached. This sandstone shows a progression from fine-grained marine sandstone with animal fragments (mainly crinoidal) at its base, through more thinly bedded sandstone with ripple cross-laminations and a mudstone/siltstone parting, to sandstone with drifted plant remains and marine fossils and, finally, a thick (7.90 m) massive sandstone with some internal channelling. The latter lithology is characteristic of the Rosa María Sandstone in the La Ojosa section (text-fig. 7), in the western flank of the Casavegas Syncline.

Correlation between Río Areños and La Ojosa sections.

A comparison between the succession described above, from Areños seam 10 to the Rosa María Sandstone, and that corresponding to the same interval in the La Ojosa section, shows a broad overall resemblance as well as important differences of detail. One of the obvious similarities between the two sections is the alternation of quiet marine basin sediments (mudstones) with shallow marine sandstones which often show evidence of eventual emergence and the establishment of *in situ* vegetation. The carbonaceous shales and the thin coal seam with their respective seat-earths in the Río Areños section correlate without apparent difficulty with seam 10 and the seat-earth at some 40 m above this seam in the La Ojosa section. In both sections the interval containing these coals and seat-earths is sandy and dominated by sedimentary structures indicative of a very shallow marine to non-marine facies. Above the thin coal (0.12 m) in the Río Areños section a gradual transgression is recorded, leading to calcareous mudstone and dirty limestone. The latter horizon can be correlated with the calcareous mudstone of loc. 2135 in the La Ojosa section. Also, the seat-earth at 98 m above seam 10 in the La Ojosa section may be correlated with the seat-earth at 80 m above the carbonaceous shales representing the same seam in the Río Areños section. As a marked difference, however, the intervening succession is more sandy and thinner in the Río Areños section which also shows evidence of instability in the occasional flakes of mudstone incorporated in siltstone layers and, perhaps, also in the presence of the ball and pillow structures. It could be surmised that the Río Areños sequence was formed nearer to the shore and that the corresponding part of the La Ojosa section was laid down in a more central part the basin. Differential subsidence may then be regarded as a possible factor in producing a thicker accumulation of strata in the La Ojosa section. This ties in reasonably well with evidence for thinning in a south-eastern direction which has been recorded for part of the sequence above the upper Casavegas coals (compare page 556).

Rosa María coals.

The top part of the Rosa María Sandstone in the continuation of the Río Areños section first shows the incoming of drifted plant remains (in the uppermost 0.90 m), and then the gradual introduction of rootlets which become gradually more abundant upwards and form a seat-earth for the first Rosa María coal, 0.15 m thick. This coal has been subject to exploratory workings in this area (loc. 2150 - compare page 570).

The first Rosa María coal is followed by clay with coaly streaks and some carbonaceous shales as well as another thin smut (0.11 m thick) which represents the second Rosa María coal. As in the La Ojosa section, which it closely resembles, this section then shows a subsequent sandstone which first contains a few rootlets as well as abundant drifted plant remains and then drifted plant debris only. This sandstone of continental facies shows the effects of a gradual transgression by the progressive introduction of animal fragments, at first accompanied by drifted plant debris but later occurring alone. At a somewhat higher level, drifted plant remains re-appear and silty mudstones with animal remains alternate with more sandy deposits with plant fragments.

Urbaneja Limestone.

A higher succession than that recorded in the La Ojosa section is found north of Urbaneja (text-fig. 1), in the continuation of the Río Areños section. The advent of slightly silty and silty mudstones, with some calcareous intervals and very rare siltstone and sandstone partings, shows the subsequent establishment of a quiet marine basin above the Rosa María coal horizon. The whole of this sequence is fossiliferous and some horizons are quite rich in fossils, with lamellibranchs, brachiopods, crinoids, gastropods, bryozoa, etc. At the top of this mudstone sequence a variable thickness of brecciated limestone is found. This represents an allochthonous deposit formed by large blocks of limestone and individual worn limestone fossils in a mudstone matrix. Amongst the fossils, crinoids and sponges are particularly common. Between Lores and Urbaneja (text-fig. 1) the Casavegas Syncline splits into two smaller synclines, the eastern one of which shows the allochthonous slide limestone (terminology according to READING 1970) in both flanks. The eastern limb of this accessory syncline shows some 22 metres of slide limestone, whilst the western limb contains a much thicker development, up to 96 metres altogether. From this slide limestone, called the Urbaneja Limestone by VAN GINKEL (1960), algae were studied by RÁCZ (1966), who compared the assemblage with that of a Kasimovian limestone near the village of Vañes, further to the south (compare VAN GINKEL 1965, p. 197). Sponges from the Urbaneja Limestone (loc. 2063) were identified as *Cystauletes mammilosus* KING by Dr. W. J. E. VAN DE GRAAFF (pers. comm.).

A tentative correlation with limestones at the same stratigraphic level a few kilometres south of Urbaneja, suggests that the slide limestone of Urbaneja exists as an autochthonous limestone deposit to the south and south-east. It thus appears likely that a nearby basin flexure may be held responsible for the brecciation and mass transport of the Urbaneja slide limestone into the basin.

Correlations and higher succession

The maximum sequence of *ca.* 2,300 metres of strata developed in the Casavegas Syncline (text-fig. 1) has been discussed above. Apart from *ca.* 100 metres of small fining upwards rhythmic units at the base of the succession north-west of Casavegas, the general succession is characterized by coarsening upwards sequences, sometimes including limestones and coals. Thickness changes have been observed mainly in the intermediate mudstone units, and both the trangressive calcareous mudstone/limestone horizons and the regressive seat-earth and/or coal beds (usually following upon sandstone), have proved to be constant within the confines of the Casavegas Syncline. These are therefore the horizons which can be traced in the field and represented on a geological map.

The steady and fairly considerable plunge southwards of the Casavegas Syncline assures the incoming of higher measures, i. e. above the Rosa María coals and the Urbaneja Limestone, in the region of San Salvador, Verdeña, Vañes and San Felices de Castillería (text-fig. 10). This area has been investigated most recently, and after the illustrations for the present paper had been prepared. These investigations are also being continued, and only a tentative outline of the correlations suggested by the preliminary results will be given in the following pages.

San Salvador coals.

The direct tracing southwards of the Rosa María coals and of the accompanying Rosa María Sandstone at Urbaneja has not been possible because they are obscured by the floodplain of the Río Pisuerga. However, it is clear that the Rosa María coals represent an horizon well below that of a coal-measure sequence which occurs north and east of San Salvador de Cantamuda (text-fig. 11). These San Salvador coals have been investigated south-east of San Salvador, where an important limestone (Verdegosa Limestone of NEDERLOF 1960) is followed by silty mudstones with siltstone and sandstone partings (*ca.* 80 m) and then by predominantly sandstones, with two coal seams and their accompanying seat-earths. Comminuted plant debris is common throughout the mudstone/siltstone and subsequent sandstone sequence. Only at one horizon, 17.50 m above the second coal, have marine fossils been observed (crinoids and lamellibranchs). In the measured section identifiable plant remains proved to be scarce, but *Neuropteris ovata* HOFFMANN and *Neuropteris scheuchzeri* HOFFMANN were found in the interval between 23.50 m and 28 m above the second San Salvador coal.

The San Salvador coal horizon is easily recognized because of the association of two closely spaced coal seams and seat-earths with over 40 m of sandstones showing ripple cross-laminations, current bedding and channelling. Particularly characteristic is a markedly current bedded unit at some 13 m above the coals. These sandstones and coals can be traced east of San Salvador into a hill NE of this village, where there is a marked change in the strike to WNW, and then into exposures north of San Salvador (text-fig. 10). There is no doubt that the San Salvador horizon is higher in the succession than the Rosa María coals, but the exact stratigraphic separation is unknown. The Verdegosa Limestone, underlying the San Salvador coals by some 100 m at least, may be the equivalent of the Urbaneja Limestone, well above the Rosa María coals,

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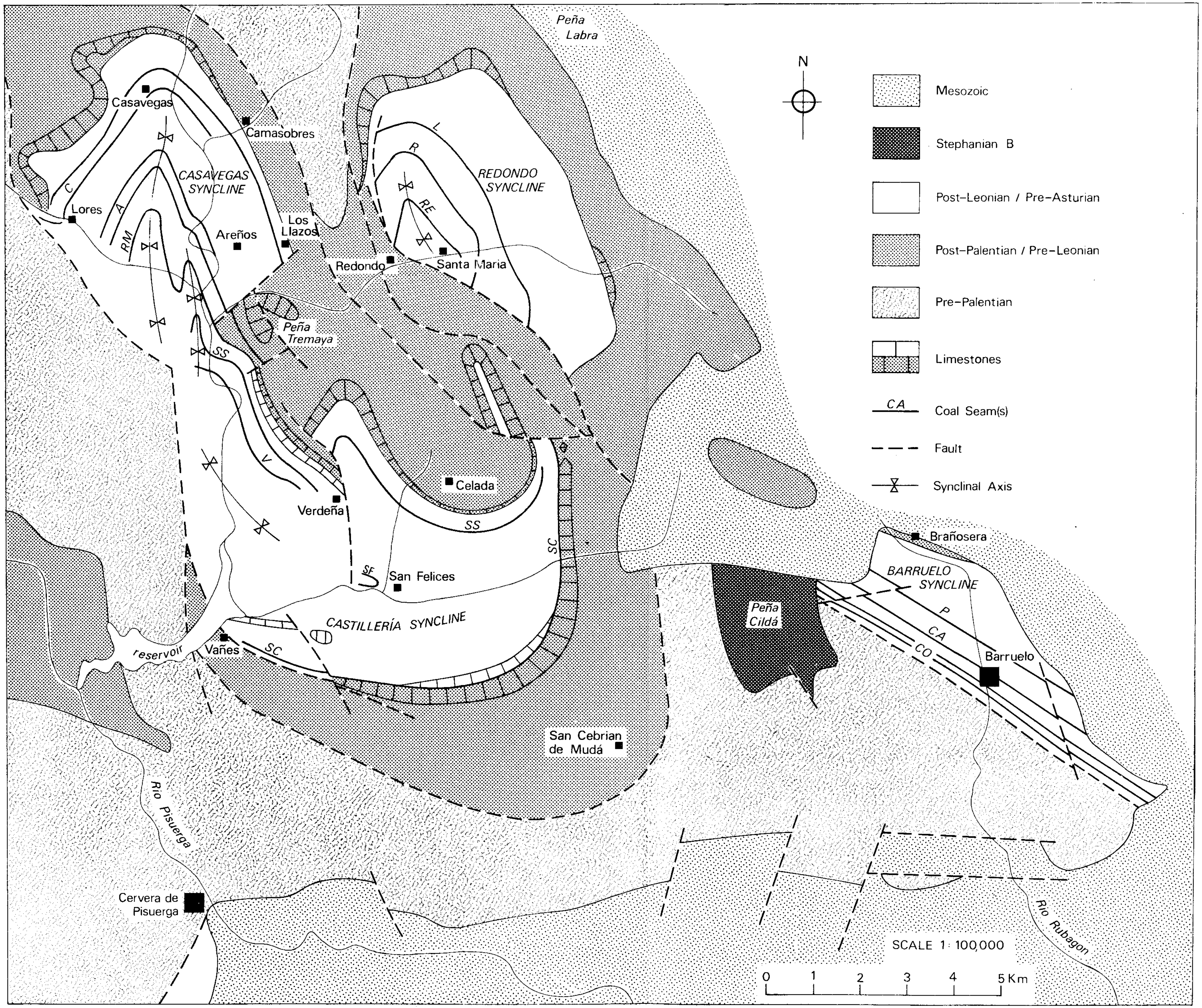
Text-fig. 10.—General geological map of northern Palencia which shows the distribution of post-Leonian strata in relation to other sequences limited by major unconformities. The pre-Palentian rocks range in age from Silurian to lower Westphalian, the post-Palentian strata from upper Westphalian B to Westphalian D, the post-Leonian deposits from upper Westphalian D to Stephanian A, and the post-Asturian strata belong to the Stephanian B. The different coal horizons in the post-Leonian succession are identified as follows: C —Casavegas, A —Areños, RM —Rosa María, SS —San Salvador, V —Verdeña, SC —San Cristóbal, SF —San Felices, L —Lomba, R —Redondo, RE —Reboyal, P —Peñacorba, CA —Carboneros, CO —Calero. This map is partly based on those published by WAGNER 1960 and DE SITTER & BOSCHMA 1966.


Peña Labra
N
Mesozoic
Stephanian B
Post-Leonian / Pre-Asturian
Post-Palentian / Pre-Leonian
Pre-Palentian
Limestones
CA
Coal Seam(s)
Fault
Synclinal Axis
Casavegas
Camasobres
CASAVEGAS SYNCLINE
REDONDO SYNCLINE
Lores
Areños
Los Llazos
Redondo
Santa Maria
Peña Tremaya
Celada
Verdeña
SS
SC
SF
San Felices
CASTILLERÍA SYNCLINE
reservoir
Vañes
Brañosera
BARRUELO SYNCLINE
Peña Cildá
P
CA
CO
Barruelo
San Cebrian de Mudá
Rio Pisuerga
Cervera de Pisuerga
Rio Rubagon
SCALE 1: 100,000
0 1 2 3 4 5 Km

but it may also represent a somewhat higher horizon. Further mapping in the San Salvador area will be necessary to solve this problem.

The San Salvador coals have been worked from an inclined shaft (abandoned) east of the main road from Cervera to Potes (Mina Pedrito as mentioned in NEDERLOF & DE SITTER 1957) and another shaft was built near the Pisuerga riverbed at some 750 m SE of San Salvador. A spoil heap near the road bridge north of the second shaft produced the following plant fossils (loc. 2183 — R. H. W. *det.*):

Neuropteris scheuchzeri HOFFMANN.
Alethopteris bohemica FRANKE.
Alethopteris lesquereuxi WAGNER.
Alethopteris grandinioides var. *subzeilleri* WAGNER.
Sphenopteris sp.
Pecopteris arborescens (VON SCHLOTHEIM) BRONGNIART.
Pecopteris sp. div.
Lepidodendron sp. nov.? (cf. *scutatum* LESQUEREUX).

The presence of *Alethopteris bohemica* is important since this is a Stephanian species which appears only rarely in the lower Cantabrian (WAGNER, VILLEGAS & FONOLLÁ 1969) and which gradually becomes more frequent from approximately middle Cantabrian onwards. A Stephanian age is also suggested by *Pecopteris arborescens*, whilst *Neuropteris scheuchzeri*, *Alethopteris lesquereuxi* and *A. grandinioides* var. *subzeilleri* tend to indicate an horizon not too far above Westphalian D. This flora may therefore be attributed to either lower or middle Cantabrian. The composition of this flora is in keeping with the local occurrence, even though the provenance of the material cannot be guaranteed.

Verdeña coals.

The prominent sandstones of the San Salvador coal horizon are followed by another mudstone sequence, which has not yet been investigated in detail. A subsequent coal horizon is here recorded as the Verdeña coals. These may represent only the upper part of the «grupo de Verdeña» as mentioned by NEDERLOF & DE SITTER (1957), who combined the San Salvador and Verdeña coals in one unit.

No detailed investigation of the Verdeña coals has been made yet, but it appears likely that these coals were worked by the (abandoned) Sanfesa Mine (probably the Mina San Francisco of NEDERLOF & DE SITTER — Sanfesa being the name of the Company). The tip of this mine, east of San Salvador de Cantamuda, yielded well preserved plant fossils (loc. 2208 — R. H. W. *det.*):

Neuropteris ovata HOFFMANN var. *ovata*.
Neuropteris scheuchzeri HOFFMANN.
Alethopteris bohemica FRANKE.
Alethopteris grandinioides var. *subzeilleri* WAGNER.
Pseudomariopteris ribeyroni (ZEILLER) DANZÉ-CORSIN.

Dicksonites pluckeneti (VON SCHLOTHEIM) STERZEL.
Nemejcopteris (Pecopteris) feminaeformis (VON SCHLOTHEIM) BARTHEL.
Pecopteris bioti BRONGNIART.
Sphenophyllum nageli GRAND' EURY.
Sphenophyllum emarginatum BRONGNIART.
Lepidophyllum triangulare ZEILLER.

The rare first occurrence of *Nemejcopteris feminaeformis* (a single specimen found by Dr. A. BOUROZ during the field meeting in September 1970) clearly indicates a Stephanian age. This species had not, thus far, been recorded below Stephanian A (*sensu stricto*) (compare BOUROZ, GRAS & WAGNER 1970, p. 216), but the flora discussed here must be regarded as definitely older than Stephanian A. It contains *Neuropteris scheuchzeri* HOFFMANN which ranges into upper Cantabrian but apparently not beyond this horizon in Northwest Spain (compare WAGNER & WINKLER PRINS 1970). In addition, the presence of *Sphenophyllum nageli* invites comparison with zone 2 (Panissière) of the Cévennes in southern France (BOUROZ *et al.* 1970) which has been correlated with the higher part of the Cantabrian in N. W. Spain (*op. cit.*).

San Cristóbal coals.

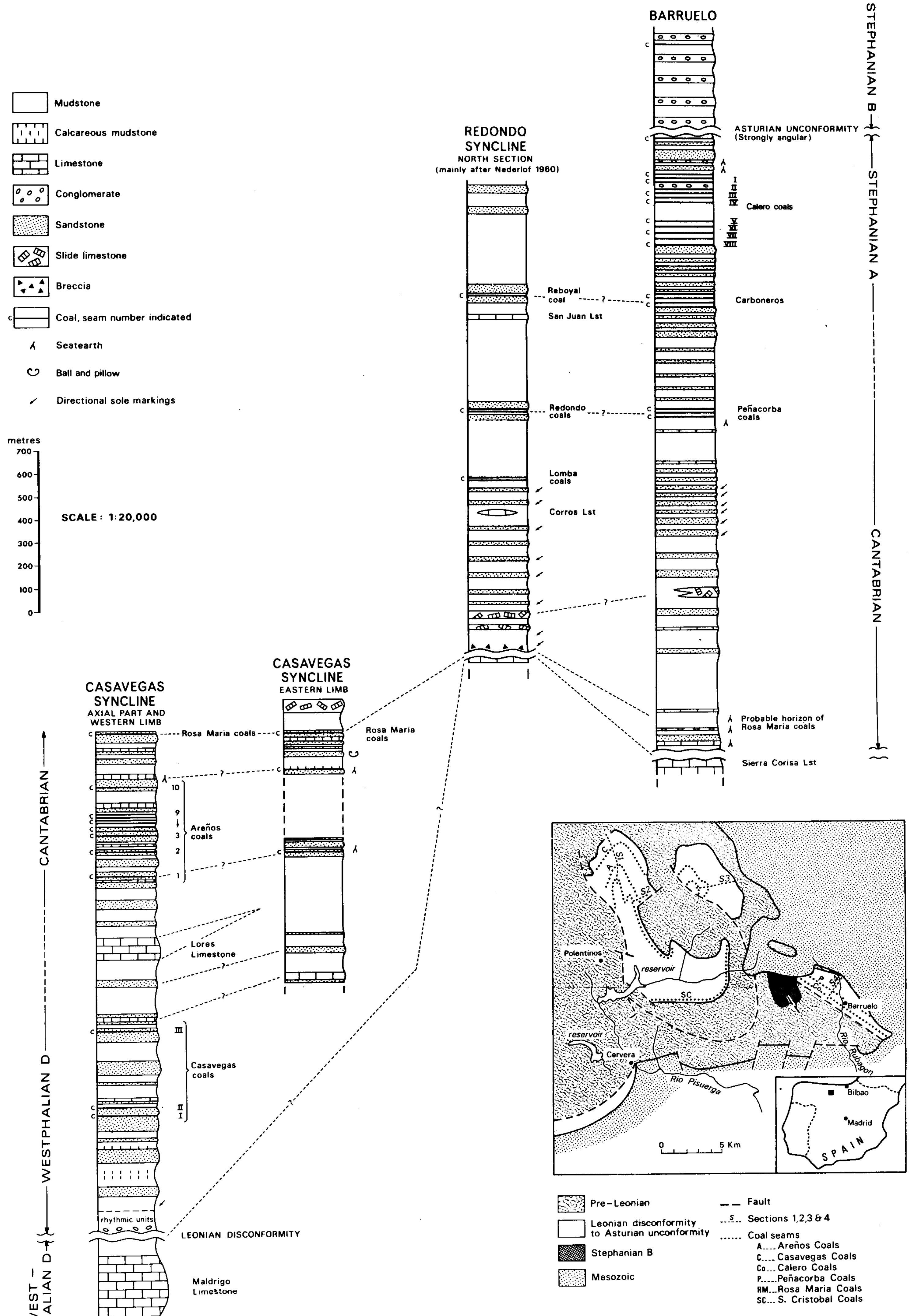
Although a precise correlation has not yet been made, it appears very likely that the Verdeña coals are the equivalent of the San Cristóbal coals in the San Cristóbal Hill south-east of Vañes (text-fig. 10). These coals crop out on the hillside and fossils can be collected from exposures, tips and collapsed workings. One of the coals is intruded by a dyke and is locally cokified. A composite list of plant fossils from the San Cristóbal Hill has recently been published by the first author *in* WAGNER & WINKLER PRINS (1970, p. 500).

An additional plant locality was discovered by Dr. W. J. E. VAN DE GRAAFF at the shore of the reservoir just north of Vañes. It contains the following species (loc. 2071 — R. H. W. *det.*):

Linopteris cf. *neuropteroides* (VON GUTBIER) POTONIÉ.
Linopteris cf. *gomesi* TEIXEIRA.
Callipteridium (Praecallipteridium) jongmansi (P. BERTRAND) WAGNER.
Alethopteris grandinioides KESSLER var. *grandinioides*.
Alethopteris lesquereuxi WAGNER.
Palaeopteridium reussi (VON ETTINGSHAUSEN) KIDSTON.
Lobatopteris vestita (LESQUEREUX) WAGNER.
Pecopteris cf. *elaverica* ZEILLER.
Pecopteris sp.
Annularia stellata (VON SCHLOTHEIM) WOOD.

The flora from the San Cristóbal coal horizon has been assigned a middle Cantabrian age (WAGNER & WINKLER PRINS 1970) and this new locality does not contain any elements which would cause this assessment to be altered.

Correlation diagram of post–Leonian successions in Northern Palencia comprising the interval from Upper Westphalian D to Stephanian A



Text-fig. 11.—General correlation diagram of the post-Leonian strata in northern Palencia.

Vañes Limestone.

The San Cristóbal coal horizon is overlain by entirely marine strata which contain a major limestone. This is exposed particularly well along the reservoir immediately north of Vañes, where it contains abundant fossils, e. g. foraminifera, algae, corals, gastropods, crinoids. The fusulinid foraminifera from localities in and above the Vañes Limestone were studied by van Ginkel (1965, loc. P 36 and loc. P. 99), who recorded an assemblage of lower to middle Kasimovian age (*Protriticites* Zone).

San Felices coals.

Probably well over 1,000 metres of strata separate the San Cristóbal coal horizon from the San Felices coals. The latter represent the highest coal-measures in the Castillería Syncline which continues the Casavegas Syncline south-eastwards (text-fig. 10). The old spoil heaps near San Felices de Castillería have yielded an important flora which has been listed most recently in Wagner 1964 (p. 839, Table III), and which has been regarded as upper Cantabrian in age.

Post-Leonian succession in the Castillería Syncline.

The most complete succession of post-Leonian strata in the Castillería Syncline is exposed along the road from San Felices to Celada de Roblecedo and in the valley followed by this road. Only the lower part of this succession has been investigated, and this has proved to be correlatable with the sandstone below the Verdegosa Limestone (tentatively regarded as being equivalent to an horizon close to or identical with the Rosa María Sandstone and coals), the Verdegosa Limestone itself (here developed mainly as a calcareous mudstone with an almost negligible amount of limestone) and with the sequence up to and including the San Salvador coals. There is no detailed record yet of the succession above this coal horizon, but it appears that turbidites appear well before the San Felices coal horizon is reached. The succession along the San Felices — Celada road has been diagrammatically illustrated by Nederlof (1960, enclosure 2, section 5), but the published section has proved to be too incomplete to be useful for correlation.

Correlation with the Río Rubagón section at Barruelo.

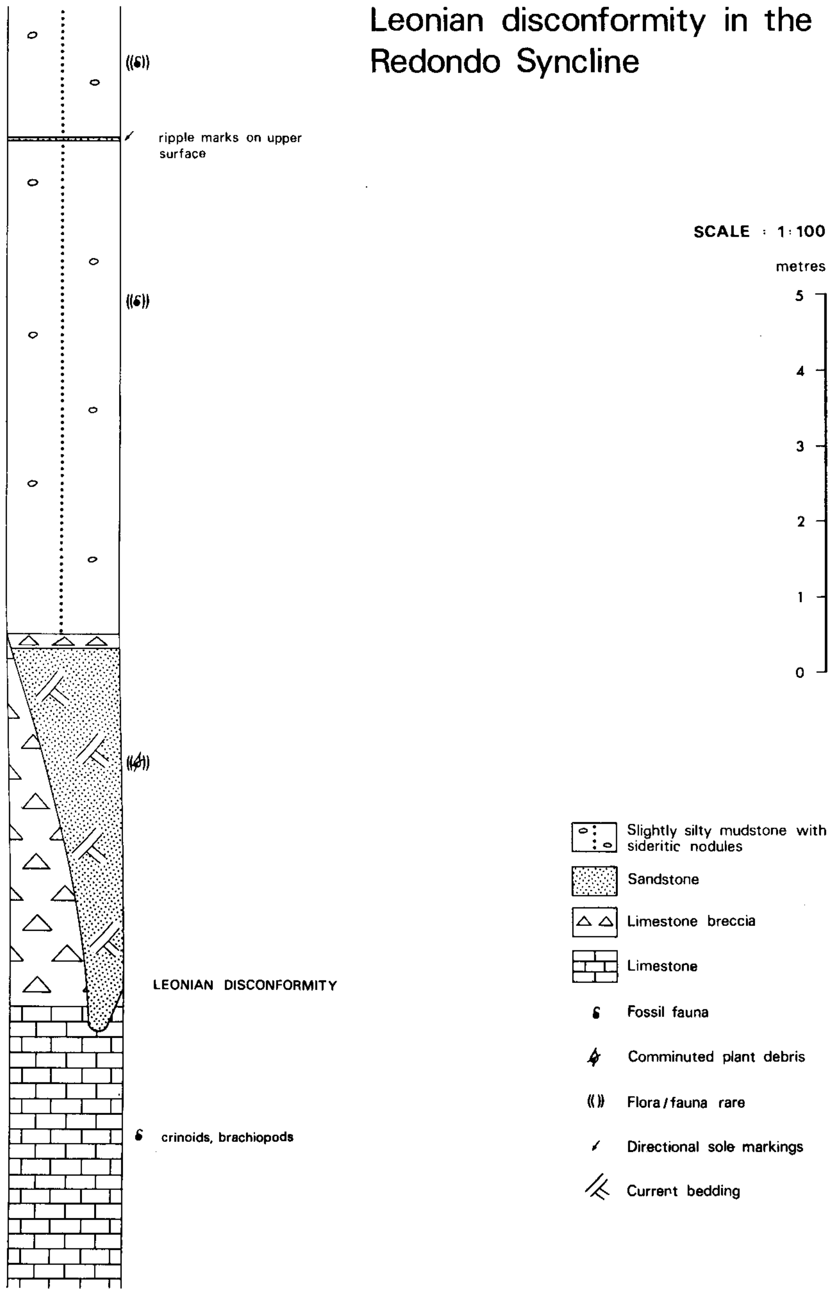
On the assumption that the Verdeña (San Cristóbal) coals will be present in the Celada road section and taking into consideration the presence of turbidites higher up in the succession, there is reason to correlate with the known sequence at Barruelo de Santullán (compare Wagner & Winkler Prins 1970, text-fig. 3), particularly since the flora of San Felices is apparently similar in age to that of the Peñacorba coal-measures in the Barruelo area. The base of the succession at Barruelo has been compared with that on the southern and eastern limbs of the Castillería Syncline (*op. cit.*), and several seat-earths found near the base of the Barruelo section have been correlated tentatively with the San Cristóbal (Verdeña?) coals. An important development of turbidites higher in the Barruelo section may represent the turbidite sequence in the San Felices — Celada road section, below the San Felices coals. Similarly, the Peñacorba coals lie a few hundred metres above the turbidites in the Barruelo section.

At Barruelo de Santullán an additional 1,200 metres of strata are developed above the horizon of the Peñacorba coals. These contain two coal-measure horizons (Carboneros and Calero, respectively) which have yielded floras of Stephanian A age (*sensu stricto*). The Barruelo section has also yielded brachiopod faunas of Kasimovian age (WAGNER & WINKLER PRINS 1970), which proves that Kasimovian equates to Stephanian A as well as middle to upper Cantabrian.

In text-fig. 11 the basal part of the succession at Barruelo has been correlated conservatively with the Rosa María coal horizon. Later information, obtained after the correlation diagram was drawn, favours a position well above the Rosa María horizon, and this means that the already remarkably thick succession of upper Westphalian D, Cantabrian and Stephanian A rocks in northern Palencia is even thicker than the diagram of text-fig. 11 suggests. As a conservative estimate, one may regard the total succession of post-Leonian strata as being some 5,000 metres thick in maximum development.

Succession in the Redondo Syncline.

Little work has yet been done in the Redondo Syncline which forms the northwestern continuation of the Barruelo Syncline, apart from establishing the local base of the post-Leonian succession. Clear evidence for the Leonian disconformity has been found in the Pisuerga river valley at 3,300 m east of Santa María de Redondo, where a limestone regarded as a correlative of the Abismo Limestone (NEDERLOF 1960, Enclosure 2, section 10 and geol. map) is covered by an *in situ* breccia and potholed by subaerial erosion. This limestone, which may be up to 300 m thick further north, only totals some 8 m in the Pisuerga river valley. Although sedimentary wedging probably plays a rôle, some of the thinning in this locality should be attributed to the subaerial erosion which produced the limestone scree covering most of the limestone surface. This scree is up to 5 m thick in the locality examined. Interrupting the fossil scree and reaching down into the limestone, a pothole was found with a subsequent infilling of current bedded sandstone with occasional comminuted plant debris. The adjacent scree extended to seal the sandstone fill which can only be interpreted as fluviatile in origin (text-fig. 12). Immediately afterwards, the area must have been involved in rapid subsidence, for the subsequent deposits consist of slightly silty, compact mudstone with sporadic sideritic nodules and rare, indeterminate animal remains. This mudstone is interrupted at intervals by thin bands of medium-grained sandstone with directional sole markings at the base and ripplemarks at the top. They show sharp lower and gradational upper contacts and undoubtedly represent turbiditic flow deposits. Eleven metres above the fossil scree the first identifiable animal remains are found, viz. crinoids, and 0.50 m higher in the succession a lensing calcareous mudstone is encountered with corals, crinoids and probable fusulinid foram-



Text-fig. 12.—Stratigraphic section through the Leonian disconformity (marked by a karst surface) and succeeding mudstones with thin turbiditic sandstones in exposures at *ca.* 3.5 km ESE of Santa María de Redondo.

inifera. A long sequence of mudstones with thin turbiditic sandstone bands (generally 1-15 cm thick), at intervals varying between 3 and 24 metres, shows fossil horizons with varied faunas: crinoids, corals, brachiopods, gastropods, bryozoa, lamellibranchs, etc. Eventually, important bodies of slide limestone composed of large blocks «floating» in a mudstone matrix are added to the sequence, and increase the general impression of rapid subsidence accompanied by an appreciable basin slope. These are the limestone breccias due to submarine sliding reported by NEDERLOF (1960, pp. 615-616 — slide breccia of Pozo del Diablo) and by READING (1970, p. 35, fig. 7).

These slide limestones are similar to those found near Urbaneja, in the Casavegas Syncline (eastern limb), and to those in the Río Rubagón section near Barruelo, where they occur well above the base of the post-Leonian succession (see text-fig. 11). These is, of course, no guarantee that the three slide limestones mentioned will prove to be synchronous. The tentative correlations established thus far suggest, in fact, that the Urbaneja slide limestone is older than others of the same facies. One similarity between the slide limestones of Pozo del Diablo in the Redondo Syncline and that of the Río Rubagón section at Barruelo is that in both cases they occur at the base of an important turbidite succession.

The general section for the Redondo Syncline, as published by NEDERLOF (1960), shows the subsequent development of three coal horizons, viz. the Lomba, Redondo and Reboyal coals (text-fig. 11). The first workable coal horizon in the Barruelo section is at the level of the Peñacorba coals but it should be noted that an old coal tip in the Rubagón valley indicates the probable presence of coal at a lower horizon. The flora collected from the Redondo coal horizon (WAGNER 1955, p. 164) invites comparison with the Peñacorba flora and it appears likely that the Redondo coal horizon should be correlated with the Peñacorba coal beds. The Reboyal coals would thus be the probable equivalent of the Carboneros in the Barruelo section. If this correlation proves to be acceptable, a major problem is posed by the absence of the Calero coals of Barruelo in the Redondo sequence (text-fig. 11). The amount of palaeontological information available from the coal-bearing parts of the succession in the Redondo Syncline is very small however, and a correlation on this basis with the coal-bearing sequences at Barruelo may well be regarded as inadequate. At present, the principal basis of a correlation between the Barruelo and Redondo sections is found in the important turbiditic sequences which have been regarded as synchronous or approximately synchronous in these two sections. Should this not be the case, then the Barruelo section would have to te moved upwards and a correlation sought, perhaps, between the Reboyal coal and the seat-earths at the base of the Barruelo succession. Such a correlation would however add a further 2,000 metres to a succession which is already some 5,000 metres thick on the more conservative, tentative correlation as presented in text-fig. 11.

Some support is given to this correlation by a cineritic horizon within one of the Redondo coals. This rock, which has been identified by Dr. A. BOUROZ (pers. comm.) as a Type IV Cinerite, is similar to a cinerite collected by Dr. BOUROZ from the tip of the Peñacorba Colliery at Barruelo de Santullán. Since the same kind of cineritic rock may however occur at different horizons within the stratigraphic sequence, these two occurrences may not be sufficient to substantiate a correlation between the Redondo and Peñacorba coal horizons. Proof of this correlation will have to wait until a succession of cinerite bands can be established for both the Redondo and Barruelo sections.

BASIN CONFIGURATION

DE SITTER & BOSCHMA (1966, p. 235, fig. 23) proposed a number of basins in northern Palencia, separated by ridges controlling the sedimentation. They also described these basins as being controlled by tilted blocks and generally sought to equate major tectonic fault zones, as found at present on the geological map, with the proposed ridges controlling sedimentation. The amount of stratigraphic information available to DE SITTER & BOSCHMA was however inadequate for these palaeogeographic conclusions. The faults interpreted as ridges appear to be later than the sedimentation which they are supposed to have controlled.

The detailed investigations undertaken by the present writers have not been able to confirm the basins and ridges as proposed by DE SITTER & BOSCHMA, but they do support the general assumption that vertical movements controlled some of the basin configuration (not however in the position envisaged by the authors mentioned). It is in fact probable that during the time from upper Westphalian D to lower Stephanian (*sensu lato*) there was but a single basin in northern Palencia. This basin spread gradually eastwards (and south-eastwards?) in the course of lower Stephanian times.

The initial basin was established in the north-western part of the area studied, in the region of Casavegas and Lores (text-figs. 1, 10), where two basin sags are visible as locally downwarped areas bounded by flexures which show up very well in the underlying, pre-Leonian, Maldrigo Limestone. It has already been mentioned (p. 542) that in this area there is no appreciable time gap associated with the Leonian disconformity in the most complete post-Leonian succession outcropping in the basin sag near Casavegas. This may lead to speculation as to whether an uninterrupted Westphalian D succession, without a Leonian disconformity, may be present further north- or northwestwards. In a west-southwesterly direction and over a distance of some 35 kilometres, the Leonian disconformity of northern Palencia changes into an angular unconformity in north-eastern León, where several hundred metres of post-orogenic conglomerates were laid down on a mountainous relief produced as the direct result of tectonic movements. It is noteworthy that the age of the post-orogenic deposits in the folded and strongly uplifted area of north-eastern León is apparently more or less the same as that of the post-tectonic succession near Casavegas, where the Leonian movements merely represent a temporary halt in sedimentation with possibly some minor uplift. Both below and above the basal conglomerates of the post-Leonian succession near Casavegas fining upwards, rhythmic units are found, and these may reflect movements of a nearby source area. These movements may have temporarily increased in strength at the horizon of the basal conglomerates in this section (text-figs 2, 3), but the uplift may have always remained outside the area of sedimentation represented by the Casavegas/Caloca road section. It is clear, anyway, that the Leonian tectonism was of strictly limited duration, after which downwarp and sedimentation were resumed at virtually the same time in both NE León and N Palencia, the interruption at Casavegas being probably virtually nil. There is a connection between NE León and N Palencia in the Guardo-Cervera coalfield, and the palaeobotanical information available on the latter indicates a range in age from upper Westphalian D to lower Cantabrian. This suggests that it formed part of the same basin subsiding in upper Westphalian D times, extending from at least as far westwards as NE León to as far eastwards as Cervera de Pisuerga and Casavegas (text-fig. 10).

The Leonian unconformity is recorded again some 40 kilometres north in eastern Asturias (MARCOS 1967, 1968, MARTÍNEZ-GARCÍA & WAGNER 1971), where a gradual onlap is found in an easterly direction and with ages ranging from upper Westphalian D to Stephanian A.

Similarly, in the Casavegas area the basin appears to have been gradually sloping upwards in an eastern direction. It is noted that the earliest post-Leonian deposits of Casavegas are not developed at Camasobres (text-fig. 1). Further eastwards (taking into account the steep folding of the rocks in the Casavegas Syncline), the earliest post-Leonian strata have not been developed, thus suggesting a gradual onlap towards the east.

The gradual onlap of the post-Leonian basin was apparently halted for a long time at the line of an important normal fault zone which is presently exposed at Los Llazos and north of Peña Tremaya (text-fig. 1). The rocks at both sides of the Los Llazos Fault are steeply dipping (up to 85º) and the fault zone is therefore only exposed in section. It is difficult to ascertain whether or not the line of faulting on the map represents a nearly perpendicular cross section, but the steepness of the dip of the exposed fault line with regard to the adjacent strata clearly shows it to be a very steep normal fault. The approximate strike of the Los Llazos Fault may be deduced from stratigraphic considerations. At Peña Tremaya it clearly limits two areas, one of which received some 2,000 metres of strata in excess of the other, which represents the block and which was transgressed only after a considerable time interval. The latter can be equated with upper Westphalian D and most of the lower Cantabrian. A basin with upper Westphalian D and lower Cantabrian strata was therefore limited from a block area to the east which was transgressed at a later date. Since the upper Westphalian D and lower Cantabrian strata are represented in the area of Casavegas and Lores, as well as in the Guardo-Cervera coalfield, but appear to be absent near Vañes and east of San Salvador (text-fig. 10), the line of separation between the two areas appears to run approximately north-south. It is difficult to avoid the impression that the block east of the early post-Leonian basin of sedimentation was a remnant of the Cantabrian Block which extended substantially further westwards in earlier Carboniferous times (compare WAGNER 1970 and «General Account of the Field Meeting», pp. 31-37 of the present volume), and that the post-Leonian basin in northern Palencia was sharply delimited at the boundary fault with this block during upper Westphalian D and lower Cantabrian times.

It is inconceivable that the movement along this fault took place all at once. On both sides of the Los Llazos Fault the pre-Leonian strata immediately below the disconformity are essentially the same and belong to the Maldrigo/Sierra Corisa/

Abismo limestone complex and their correlatives (compare VAN DE GRAAFF 1971[b]). This proves that erosion on the block was practically non-existent, despite the fact that the presence of karst potholes at the disconformity east of the Los Llazos Fault shows that it was emergent. Evidently, the block was stable and almost at sea level. Movement along the fault only represented downthrow, with no appreciable uplift on the other side. The type of sequence formed in the basin west of the Los Llazos Fault, which predominantly consists of regressive rhythmic units initiated by a sudden transgression, is readily explained by successive movements of downwarp in an area of shallow marine deposition, occasionally filling up to give rise to terrestrial deposits. The field evidence in the zone of faulting at Los Llazos also suggests that successive movements of downthrow took place along this fault. When tracing the more competent beds on the downthrown (basinal) side of the Los Llazos Fault, it is frequently noted that the intervening incompetent mudstones show sharp inflexions which cannot be explained by the later (Asturian) folding of these beds into the Casavegas Syncline. These almost right angle bends in the strike of the now near-vertical strata may well represent the flexuring which accompanied normal faulting at the time when the beds were still unfolded. The competent beds sometimes appear to have been tilted in the fault zone before the later (Asturian) folding took place, and also this feature seems to be in character with faulting at intervals during upper Westphalian D and lower Cantabrian times. North-west of Peña Tremaya, in the bed of the Río Pisuerga, the sandstones representing the upper parts of regressive units are bunched together and may well mark the lesser subsidence within the fault zone, as compared with the basin proper on the downthrown side.

There is no evidence of conglomerates or breccias associated with the sediments deposited near the Los Llazos Fault and this is in keeping with the indications that the block was generally at sea level and suffered only a minimum of erosion. It would also tend to indicate that the depth of the sea on the downthrown side of the fault would not have been great; an observation which is confirmed by the kinds of sediment found. Individual movements of downwarp may therefore have been relatively minor in the amount of downthrow and a cliff coast may have never existed.

One could speculate upon the actual number of movements which took place along the Los Llazos Fault during upper Westphalian D and lower Cantabrian times and count the number of regressive rhythmic units or the number of more or less sudden transgressions found in the sedimentary record. Taking as an example the succession of rhythmic units in the La Ojosa section (text-fig. 7), it is found that 47 transgressive horizons can be recognized at the base of regressive rhythmic units with a total thickness of 860 metres. Ignoring compaction, this would give an average of some 18 metres subsidence per unit. If a $\times$ 2 compaction factor is taken into account for the slightly silty and silty mudstones which make up approximately half of the stratigraphic succession, a figure of 27 metres subsidence is obtained. However, this calculation is crude and may be misleading in that small movements along the fault are likely to have produced a semblance of gradual subsidence and are thus unrecorded. Indeed, the total effect of this type of movement could account for a large part of the overall movement along the fault. The figure mentioned above may therefore represent only a *maximum* of average subsidence, since it has been obtained on the assumption that all the movements of downwarp would be reflected in the sedimentary sequence and may be accounted for. Perhaps a more objective method of estimating the probable value of major movements of downwarp is to examine the rhythmic units in the Ojosa section which commence with marine deposits overlying a coal seam and which show evidence of a gradual coarsening upwards sequence leading upwards into coal again (which thus provides a datum). Particularly instructive are the rhythmic units containing Areños coals 4 and 5 in the La Ojosa section (text-fig. 8). Two major regressive sequences are present and both show a repetition of part of the more marine lower portion. Four movements of downwarp are therefore represented. A continuous sedimentary sequence appears to be represented in the 15 metres leading upwards into seam 4, whereas 14 metres are present in the more or less continuous sequence below coal 5. Compaction may account for an additional 2 metres in respect of the mudstone and some 4 metres for the coal of seam 4 in one sequence, and 1 metre for mudstone and 9 metres for coal in the other one containing seam 5. This gives some 21 metres of subsidence for the earlier rhythmic unit and some 24 metres for the later one. Since these are some of the clearest rhythmic sequences present, it may be assumed that some 20 metres subsidence along the Los Llazos Fault represents a major movement of downwarp.

The almost total lack of erosion of the block east of the Los Llazos Fault indicates that the sediment derivation must have been from the opposite side where the evidence of a Leonian orogeny has already proved the presence of a hinterland. The successive movements along the Los Llazos Fault provided for periodic flooding or deepening of the basin adjacent to the block with the concomitant withdrawal of the coastline in an approximately westward direction. A characteristic rhythmic unit would thus show offshore marine deposits following abruptly upon non-marine strata and a gradual return to nearshore marine and non-marine deposits.

The Los Llazos Fault ceased to be active at a stratigraphic level corresponding probably to that of the Rosa María coals or possibly even higher. Unfortunately, the exposures west of Peña Tremaya are insufficient to allow the local base of the post-Leonian succession to be established where it finally extended across the fault. However, the beds above the Rosa María coals certainly passed over the site of the earlier fault and continued the onlap of the basin which had been temporarily halted at the Los Llazos Fault. On both sides of this fault, and representing very different stratigraphic times, the onlap was exceedingly gradual (compare text-figs. 1, 10).

The structure of Peña Tremaya on the south-eastern side (originally the eastern side) of the Los Llazos Fault, has long posed a problem. NEDERLOF (1960, p. 625) described it as an anticline closing at its northern end. This interpretation was maintained by DE SITTER & BOSCHMA (1966). However, this anticline would possess a plunge which is directly opposed to all the other plunges in this area. More recent work by VAN DE GRAAFF (1971b) has shown the apparent anticline to consist of two thrust slices, both younging in the same, south-western direction. They repeat a succession which VAN DE GRAAFF places well below the Maldrigo Limestone and which is Podolskian in age. The present writers interpret one of these thrust slices as showing an anticlinal closure southwards (text-fig. 1). The thrust fault between the two slices (which VAN DE GRAAFF swings round some 90° and loses in the Los Llazos Fault) probably continues north-northwestwards across the Los Llazos Fault in the post-Leonian strata at Areños, where the succession of mudstones between the Lores Limestone horizon and the first Areños coal seam appears to be markedly thickened. This suggests a similar repetition as that recorded at Peña Tremaya. As yet, however, the present writers have not illustrated this probable extension of the Peña Tremaya thrust fault across the Los Llazos syn-sedimentary fault, until the area near Areños can be re-examined and further evidence obtained.

The limestone of Peña Tremaya is followed westwards in a conformable succession by a prominent sandstone unit, which VAN DE GRAAFF (personal communication and 1971b) places in the pre-Leonian succession of Upper Westphalian strata. The present writers have been able to confirm this identification by finding an old adit in a coal seam above this sandstone. With the adit occurs a tip which yields well preserved plant remains (loc. 2172 — R. H. W. *det.*):

Linopteris obliqua (BUNBURY) ZEILLER.
Sphenophyllum emarginatum BRONGNIART.

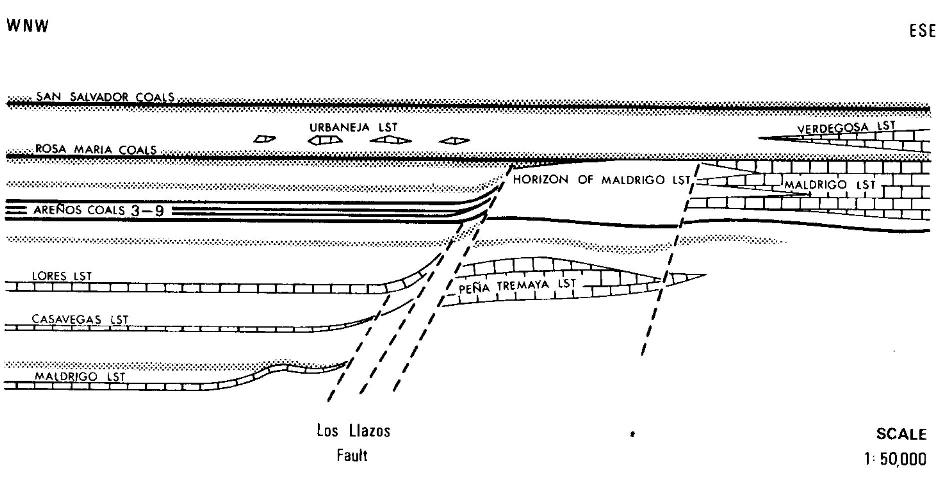
Linopteris obliqua is the most common fossil in this florule. This species is regarded as significant because it dominates most of the Westphalian C and D assemblages in Northwest Spain, and only occurs sporadically in late Westphalian D and Cantabrian strata, with a single record from Stephanian A. The associated *Sphenophyllum emarginatum* shows relatively narrow leaves which are different from the generally broader leaves of this species found in upper Westphalian D and Cantabrian rocks. If the coal seam yielding the florule cited above represented the post-Leonian succession in the area west of Peña Tremaya, it should be of lower Cantabrian age (i. e. it would be one of the Areños coals), and this would have yielded a rather different floral assemblage (compare page 567).

A general lack of exposure prevents the base of the post-Leonian succession from being established with any accuracy in the area west of Peña Tremaya. The lack of exposure however probably indicates the presence of a mudstone sequence of considerable thickness, and this tends to militate against the post-Leonian succession being present east of the road following the Río Pisuerga. Several prominent sandstones exist in that part of the post-Leonian succession which could be expected to occur here, and it is unlikely that these sandstones would not show up in the gently sloping hillside. It must therefore be concluded that no strata below the Rosa María coals extended across the Los Llazos Fault.

On the southern side of Peña Tremaya a fault is present ENE of San Salvador de Cantamuda. This fault, or a complex of faults, is represented on the map published by DE SITTER & BOSCHMA (1966), and apparently cuts off a limestone unit and two coal seams present south of the fault. One of the coals represents the San Salvador coal horizon which is not, in fact, eliminated by faulting, but which abruptly changes its strike and crosses the Pisuerga river north of San Salvador (compare text-fig. 10).

The other coal shown on DE SITTER & BOSCHMA's map may well be continued, after a relatively insignificant amount of displacement, by the coal seam of Upper Westphalian age which occurs west-southwest of Peña Tremaya and which has been discussed overleaf in relation to the sequence west of Peña Tremaya. The limestone which has been apparently cut off by the fault, is seen to divide into three bands a little before it abuts onto the fault, and is clearly wedging in a northerly direction. It is possible that the absence of this limestone horizon north of the fault is entirely due to its wedging into a mudstone sequence. This would also explain the presence of a thick mudstone sequence west of Peña Tremaya.

It is consequently suggested that the fault south of Peña Tremaya is relatively minor and merely represents another step in the series of normal faults which formed the edge of the post-Leonian basin. Text-fig. 13 shows a diagrammatic interpretation of the faulted basin margin, as deduced from the stratigraphic evidence. Since the present writers were not immediately concerned with the pre-Leonian succession, the information appertaining to the rocks below the Leonian disconformity is only to some extent based on personal observation. General stratigraphic information published in the literature and the distribution of strata as shown on DE SITTER & BOSCHMA's (1966) map, as well as on aerial photographs, have all been taken into consideration. With regard to the post-Leonian succession, the diagram has been based on the assumption that a sandstone below the Verdegosa Limestone correlates with the sandstone horizon above the Rosa María coals (thus placing the Verdegosa Limestone at the same level as the Urbaneja Limestone). This correlation is still unproven, and the possibility exists that the whole complex of Verdegosa Limestone and San Salvador coals lies at a relatively higher horizon with regard to the Rosa María coals than is shown by the diagram of text-fig. 13. The authors are also pleased to acknowledge helpful discussion on the local stratigraphy with Dr. W. J. E. VAN DE GRAAFF.



Text-fig. 13.—Diagram showing the cumulative downthrow of the Los Llazos Fault which ceased to be active at the Rosa María coal horizon.

It seems likely that the block east of the Los Llazos Fault was slightly tilted at the time when it started to subside and became incorporated in the basin of sedimentation after the fault ceased to function. This would explain the gradual onlap that took place as the basin extended eastwards in Cantabrian times. Subsequent events are still poorly documented as the correlations expressed in the columns for the Redondo Valley and Barruelo areas (text-fig. 11) are still rather tentative. The important turbidite sequences recorded in both areas for middle to upper Cantabrian strata have been studied by NEDERLOF (1960), who concluded that supply was from the north-north-east. This would tend to indicate a sharp difference in palaeogeography; for the stability and lack of significant erosion of the eastern block during the earlier part of the development of the post-Leonian basin in northern Palencia can only mean a sediment derivation from the west or south-west for the succession up to the Rosa María coals. The same pattern of sedimentation is maintained up to the Verdeña coals, with the progressive onlap eastwards indicating a general transgression of the foreland massif and thus a sediment derivation from a western or south-western hinterland area (which is in complete agreement with the evidence of much stronger tectonic activity during the Leonian Phase in the NE León area to the west). The derivation of turbidites during later Cantabrian times from an area to the east in northern Palencia would tend to indicate a rising basin margin where a stable foreland massif existed previously. The implications of this remarkable change in the palaeogeographic configuration will have to be examined at some future date, after the correlations for the later part of the stratigraphic succession have been clearly established.

LITHOSTRATIGRAPHIC UNITS

The succession of post-Leonian strata in northern Palencia consists of several lithostratigraphic units representing distinct episodes in the development of the sedimentary basin. A distinctive unit is formed by the rhythmic, fining upwards sequences which occur in 94 metres at the base of the post-Leonian succession near Casavegas and which follow upon the basal conglomerates. The latter being developed only locally, they should probably not be regarded separately but incorporated with the first lithostratigraphic unit. This unit is here named the *Rozo Formation*, after the Rozo Height in the near vicinity. Its lower limit is at the Leonian disconformity north-west of Casavegas and its upper limit is drawn at the last fining upwards sequence found in the Caloca road section (text-fig. 3). Here, a temporary increase in basin slope is marked by the presence of sporadic thin bands of turbiditic sandstone in a lithological unit which is probably not important enough to warrant recognition as a specially named lithostratigraphic unit of the same rank as the preceding one. It occurs at the base of a development of rocks which are mainly characterized by regressive, coarsening upwards, rhythmic sequences. These are developed most completely in the La Ojosa ridge (text-figs. 1, 7, 8), and it is therefore proposed to name the corresponding lithostratigraphic unit the *Ojosa Formation.** Its lower boundary lies just above the last fining upwards rhythmic unit in the Caloca road section and its top is situated beyond the Verdeña coals and below the development of turbidites which commences higher in the succession in the Castillería Syncline at a still unspecified stratigraphic level. The Ojosa Formation, thus defined, comprises well over 2,000 metres of strata and has a composite stratotype, mainly in the La Ojosa ridge but partly also in the Caloca road section, the region of San Salvador and further to the south and south-east. It is likely that the recognition of an Ojosa Formation impinges to some extent on the Brañosera Formation as described from the Rubagón Valley in the Barruelo area (compare WAGNER & WINKLER PRINS 1970). The latter should probably be restricted to the turbidites and subsequent shallow marine deposits below the Barruelo Formation as defined in the Barruelo area. Further work will be necessary to establish the limit between the Ojosa and Brañosera formations, and this involves an exact correlation between the successions in the Castillería and Barruelo synclines. Only a tentative correlation can be given at present (text-fig. 11 and pages 579-580).

The Ojosa, Brañosera and Barruelo formations jointly constitute almost the entire succession of post-Leonian strata in northern Palencia. The Rozo Formation at the base of this succession at Casavegas is only developed locally and is insignificant in terms of stratigraphic thickness. Within the three main formations it is possible to recognize several members. These have been named and described already for the Barruelo Formation by WAGNER & WINKLER PRINS (1970). For the Ojosa and Brañosera formations it is preferred to refer to the members informally as «Areños coals», «Lores Limestone», etc. and to hold a formal definition in abeyance until the total succession of rocks belonging to these formations has been described in detail.

A discussion of the post-Leonian lithostratigraphic units as used in the literature has been provided by WAGNER & WINKLER PRINS (1970), and reference is made to the relevant chapter in their paper. Most of the succession discussed in the present paper has been represented as «Cea Group» on the map published by DE SITTER & BOSCHMA (1966). This refers to an ill-defined unit comprising both post-Leonian and post-Asturian strata in Northwest Spain and its use should be discontinued (compare WAGNER 1970, p. 451).

* In 1964, BROUWER & VAN GINKEL introduced an Areños Formation which coincides almost entirely with the Ojosa Formation described here and which also has its stratotype in the La Ojosa ridge between Casavegas and Lores. At its base it has the Casavegas coals and at its top the Urbaneja Limestone (*op. cit.*, p. 314). In the interest of stability in nomenclature it would have been fitting to retain the Areños Formation of BROUWER & VAN GINKEL, if only it had not been containing, as a member, the Areños coal-measures, i.e. the «grupo de Areños» of NEDERLOF & DE SITTER (1957). This Areños Coal Member (VAN GINKEL 1965, p. 197) was assigned to the Barruelo Formation by VAN GINKEL (*loc. cit.*), who failed to mention the Areños Formation which he had introduced the year before. The attribution to the Barruelo Formation constitutes an unwarranted extension downwards of the latter which commences at a much higher level in the succession, viz. at the base of the Peñacorba coals (compare WAGNER & WINKLER PRINS 1970, and text-fig. 11 of the present paper). It seems likely that the naming of an Areños Formation containing the Areños coal-measures as a constituent member, will give rise to confusion. For this reason the Areños Formation is hereby replaced by the Ojosa Formation, thus restricting the former name to the Areños coal-measures (in agreement with the usage by NEDERLOF & DE SITTER 1957 and VAN GINKEL 1965). It should be noted that the limits of the Ojosa Formation do not entirelv coincide with those of the Areños Formation of BROUWER & VAN GINKEL.

An important aspect of the post-Leonian succession in northern Palencia is the uninterrupted development of strata ranging from upper Westphalian D to Stephanian A. No other western European locality is known to have the same continuity. BOUROZ, GRAS & WAGNER (1970) have recently analyzed the information on lower Stephanian strata *(sensu lato)* in western Europe and came to the conclusion that only the Cévennes in southern France offer a lower Stephanian succession of comparable completeness. However, the Cévennes region lacks the upper Westphalian D, and the base of the lower Stephanian can therefore not be drawn accurately in this region. In the type area of the Westphalian D, i.e. the Saar-Lorraine, the lower Stephanian is incompletely developed as a result of earth movements. A satisfactory base for the lower Stephanian in western Europe can therefore be drawn only in Northwest Spain.

It has also been noted that the traditional stratotype of Stephanian A (lower Stephanian *sensu stricto)*, as defined by P. BERTRAND (1937) and JONGMANS & PRUVOST (1950), only correlates with the upper part of the lower Stephanian *(sensu lato)* of the Cévennes and of Northwest Spain (compare BOUROZ *et al.* 1970). The lower part of the lower Stephanian *(sensu lato)* has been described as the «Cantabrian Stage» (i.e. the first stage of the Stephanian Series) by WAGNER (1966, 1969), who also proposed a composite stratotype for this chronostratigraphic unit. For the lower part of the «Cantabrian» a stratotype at Tejerina in NE León was proposed by WAGNER, VILLEGAS & FONOLLÁ (1969), whereas for the upper part the succession in the Barruelo coalfield of northern Palencia was suggested.

Although the proposed stratotype at Tejerina contains a succession of well preserved and varied impression floras which allow situating this succession with regard to the well known successions of Westphalian D and Stephanian A ages in western Europe, its detailed correlation with the post-Leonian strata in northern Palencia may be difficult to establish. It may prove more practical to have the entire stratotype for the Cantabrian in one single area, such as northern Palencia, where the detailed correlation between individual sections is now in the process of being established. A single, continuous stratigraphic sequence thus becomes available as a standard reference for chronostratigraphic purposes. The succession in northern Palencia is also generally more marine than that in NE León, and this allows a correlation not only with the non-marine areas in western Europe (by means of fossil floras), but also with regions of predominantly marine facies, e.g. European Russia and North America (by means of fusulinid foraminifera, brachiopods, etc.). It is therefore proposed here to regard the relevant part of the post-Leonian succession in northern Palencia as the stratotype of the Cantabrian (Stage or substage, depending on the Stephanian being recognized as a Series or a Stage).

Since the succession in northern Palencia is predominantly marine, the base of the Cantabrian stratotype will have to be selected more or less arbitrarily. Its approximate position is determined by the correlation which may be established between part of the floral succession found in Palencia and the floral assemblage recorded from the upper part of the type Westphalian D in Saar/Lorraine (viz. the floras from the «Zone de Faulquemont» of Lorraine and of the Heiligenwalder Schichten in Saarland).

The distribution of species recorded in *ca.* 5,000 metres of strata in northern Palencia is give in Table I, which constitutes a complete record with the exception of *Asterophyllites* and *Calamites* which are without any interest stratigraphically. Some species of *Sphenopteris* and *Pecopteris* are still unidentified, and therefore not represented in the Table.

It will be noted that the earlier part of the succession, up to and including the Casavegas coals, is characterized by the presence of a number of species which, according to CORSIN (1952, p. 95), are found for the first time in the «Zone de Faulquemont». These are: *Dicksonites pluckeneti*, *Pecopteris unita* and *Polymorphopteris polymorpha*. CORSIN adds to these *Pecopteris cyathea* (VON SCHLOTHEIM) BRONGNIART and *Pecopteris plumosa-dentata* (ARTIS)-BRONGNIART, but the former may not have been identified correctly in Lorraine and the latter constitutes a complex of species which are most probably longer ranging than upper Westphalian D and beyond. *Dicksonites pluckeneti* having been found, albeit rarely, in rocks of probable middle Westphalian D age in the central Asturian coalfield (Ablanedo Formation of the Riosa area —compare JONGMANS & WAGNER 1957), and *Pecopteris unita* being recorded from lower to middle Westphalian D onwards (WAGNER 1971), it is the presence of *Polymorphopteris polymorpha* which would seem to be more particularly significant. According to CORSIN (1952), *Pecopteris arborescens* and *Pecopteris lamurensis* (= *Lobatopteris lamuriana)* also occur in the «Zone de Faulquemont» but characterize the Stephanian A, where they become abundant. Additional species of stratigraphic interest are *Callipteridium armasi*, *Callipteridium jongmansi*, *Alethopteris lesquereuxi*, *Alethopteris robusta*, *Pseudomariopteris ribeyroni* and *Lobatopteris vestita*. The two species of *Callipteridium* have both been described from the upper Westphalian D in Lorraine (P. BERTRAND 1932) and Portugal (TEIXEIRA 1951). *Alethopteris lesquereuxi* is known from late Westphalian D rocks in South Wales, the Forest of Dean and Somerset in the British Isles, and strata of equivalent age in North America (WAGNER 1968). *Alethopteris robusta* has recently been figured from the Heiligenwalder Schichten in Saarland (GERMER, KNEUPER & WAGNER 1968) and from probably late Westphalian D beds in North America (WAGNER 1968). *Pseudomariopteris ribeyroni* is generally regarded as a Stephanian element, but occurs in late Westphalian D beds of the Forest of Dean (England) and at the horizon of the Point Aconi Seam in Nova Scotia (BELL 1938). Both in Britain and in Canada one of the most common species at this horizon is *Lobatopteris vestita* (which has been recorded from the Bristol/Somerset coalfield under the name of *Pecopteris miltoni* (ARTIS) by KIDSTON 1925), and this species is the predominant one in the post-Leonian strata up to and including the Casavegas coals. Altogether, there can be no doubt that these early post-Leonian rocks are late Westphalian D in age, and certainly not older.

As can be expected in a continuous succession, there is only a gradual change from the Casavegas coals upwards. At the horizon of the Areños coals there is generally the same floral assemblage as that recorded from the Casavegas horizon. However, *Pecopteris arborescens* and *Pecopteris melendezi* convey the impression of slightly younger rocks, of post-Westphalian D age. The flora recovered from the Areños coal horizon is probably not complete enough to permit a clear change to be admitted, and one should look at the Areños flora with regard to its position in the stratigraphic sequence in order to come to any conclusion as to its probable position at the base of the Stephanian (*sensu lato*) or at the extreme top of Westphalian D.

No such doubt attaches to the floras recorded from the Verdeña and San Cristóbal coals. From this horizon a fairly large assemblage has been obtained and a number of exclusively Stephanian floral elements are recorded: *Nemejcopteris feminaeformis*, *Lobatopteris viannae*, *Alethopteris bohemica*. These occur in association with several species «inherited» from the older assemblages, and which seem to have their latest occurrence at this horizon: *Alethopteris lesquereuxi*, *Alethopteris grandinioides*, *Sphenophyllum guerreiroi*. Of considerable stratigraphic interest are also: *Alethopteris barruelensis* and *Sphenophyllum nageli*. It should be noted that the single specimen found of *Nemejcopteris feminaeformis* is considerably in advance of the main stratigraphic occurrence of this species which is not recorded again until the Carboneros horizon. From this horizon onwards it occurs fairly commonly. *Alethopteris bohemica* reappears fairly regularly in the successive horizons, but apparently reaches a maximum of occurrence in the Calero horizon and beyond this horizon, in Stephanian B. *Lobatopteris viannae* also becomes more common in the beds higher than the Verdeña/San Cristóbal horizon. *Alethopteris barruelensis* first occurs at San Cristóbal and reappears in the San Felices, Peñacorba, Carboneros and Calero horizons. Its highest occurrence in NW Spain is at Sabero (compare Knight 1971). Finally, *Sphenophyllum nageli* is a species recorded from lower Stephanian (*sensu lato*) beds in the Cévennes coalfield of southern France, where it occurs almost exclusively in Zone 2 (Panissière) (compare Bouroz, Gras & Wagner 1970, Gras 1970). A single specimen comparable with *Sphenophyllum nageli* has been found in the Calero beds, but the only undoubted occurrence is at the Verdeña horizon. This species has been figured from lower Cantabrian rocks north of Tejerina (León) under the name of *Sphenophyllum* sp. (cf. *verticillatum* von Schlotheim) (Wagner 1964, pl. I, figs 3, 3a).

The Verdeña/San Cristóbal horizon is clearly of lower Stephanian (*sensu lato*) age and so are the succeeding 2,500 metres of strata as recorded in the Barruelo Syncline (compare Wagner & Winkler Prins 1970). Only the upper part of the succession at Barruelo can be regarded as equivalent in age to the Stephanian A (*sensu* Assise de Rive-de-Gier—compare Jongmans & Pruvost 1950) and comparison has been made with Rive-de-Gier and the lower part of the succession in the Carmaux coalfield of France (Bouroz, Gras & Wagner 1970, Fig. 2).

Whereas no doubt can be entertained about the lower Stephanian (*sensu lato*) age of the Verdeña/San Cristóbal horizon, the lower limit of the Stephanian in northern Palencia is in question. It would seem that the Casavegas coals can still be attributed to the highest Westphalian D, although practically all the plant species encountered up to and including the Casavegas coals, persist into the early part of the lower Stephanian (*senso lato*). However, it is noted that the specimens of *Callipteridium (Praecallipteridium) jongmansi* obtained from loc. 2064 (page 550), corresponding to the upper Casavegas coals, show a degree of evolution which appears consonant with late Westphalian D or, rather, with a stratigraphic horizon below that of the lower Cantabrian (i.e. basal lower Stephanian). The present writers therefore tend to admit an upper Westphalian D age for the post-Leonian succession up to and including the Casavegas coals, even though it is true that a better knowledge of the type Westphalian D floras in Saar/Lorraine would be desirable before the Casavegas coals are definitely assigned to Westphalian in preference to lower Cantabrian (basal Stephanian).

Although the Areños coals, with fossil floras recorded at some 800 metres above the upper Casavegas coals, are not clearly different in age from the latter, it is likely that further collecting will reveal differences which are not so readily apparent from the rather poor collections available at present. Nevertheless, the presence of *Pecopteris arborescens* and *Pecopteris melendezi* tends to indicate a stratigraphic level beyond Westphalian D. Tentatively, it is proposed here to regard the Areños coals as basal Stephanian (lower Cantabrian), and to designate the lower limit of the chronostratigraphic unit (Cantabrian) in its stratotype at some clearly marked horizon in the local succession. The base of the Lores Limestone would seem to be a suitable marker for this lower limit to the Cantabrian Stage (or substage) in its proposed stratotype. A boundary of this kind is of necessity somewhat arbitrary and it should be noted that this boundary, if accepted, would delimit the upward range of Westphalian D, regardless of the extent of Westphalian D rocks which may be found eventually under the Holz Conglomerate in Saar/Lorraine. This means that, even though every care should be taken to ensure that the upper Westphalian D in northern Palencia corresponds closely to the upper Westphalian D in its generally accepted floral characteristics (as reported from Saar/Lorraine), it is the base of the succeeding chronostratigraphic unit which determines the top of Westphalian D. Otherwise, a situation could arise whereby Westphalian D could be expanded considerably upwards as new and higher horizons are found below the Holz Conglomerate. It is in the interest of a stable stratigraphic usage that the Westphalian D should not be expanded upwards beyond its generally accepted boundary (and floral characteristics).

In the discussion about the stratigraphic age of the post-Leonian strata up to and including the Casavegas coals, no mention has been made of *Neuropteris planchardi* which has been found in loc. 1910, well below the lower Casavegas coals. This species, which is a well known element of middle and upper Stephanian floras in France, has been found on three occasions in marine rocks of considerably earlier age in Northwest Spain (compare WAGNER, JONES, SPINNER & WAGNER-GENTIS 1970, and WAGNER & WINKLER PRINS 1970). *Neuropteris planchardi*, like the closely similar species *Neuropteris gallica* ZEILLER, appears to be «flözfernes» and should probably not be taken into consideration when a stratigraphic age is deduced from floral assemblages derived from a swamp environment. These species probably lived on hill slopes and were only occasionally incorporated with sediments preserving the local swamp flora. *Neuropteris planchardi* is therefore disregarded in the discussion on the stratigraphic age of the probable upper Westphalian D strata, in which it has been found in the Casavegas Syncline.

It has already been mentioned that the predominantly marine succession of lower Stephanian rocks in northern Palencia provides an ideal opportunity for correlation with marine Carboniferous rocks in European Russia. Perhaps the most important fossils for such a correlation are the fusulinid foraminifera which permit dating in terms of Moscovian and Gzhelian chronostratigraphic units. The fusulinid faunas in northern Palencia have been studied by VAN GINKEL (1965), who obtained Myachkovian faunas from the Lores Limestone and from a limestone lens in the lower part of the Areños coal horizon. These belong to the *Fusulinella* B_3 subzone of VAN GINKEL. Assemblages of the Kasimovian *Protriticites* Zone were reported from the Vañes limestone above the San Cristóbal coal horizon, and from the Corros Limestone in the Redondo section. The limestone lens near the base of the Areños coal horizon and the Vañes Limestone are approximately 1,000 metres apart in the stratigraphic succession and the Myachkovian/Kasimovian (Moscovian/Gzhelian) boundary lies somewhere in this long interval.

Additional information was obtained by RÁCZ (1966), who investigated the calcareous algae in thin sections made available by VAN GINKEL, and who stated the presence of a similar assemblage to that of the Vañes Limestone in the Urbaneja Limestone. It may therefore be assumed that the Urbaneja Limestone also belongs to the Kasimovian.

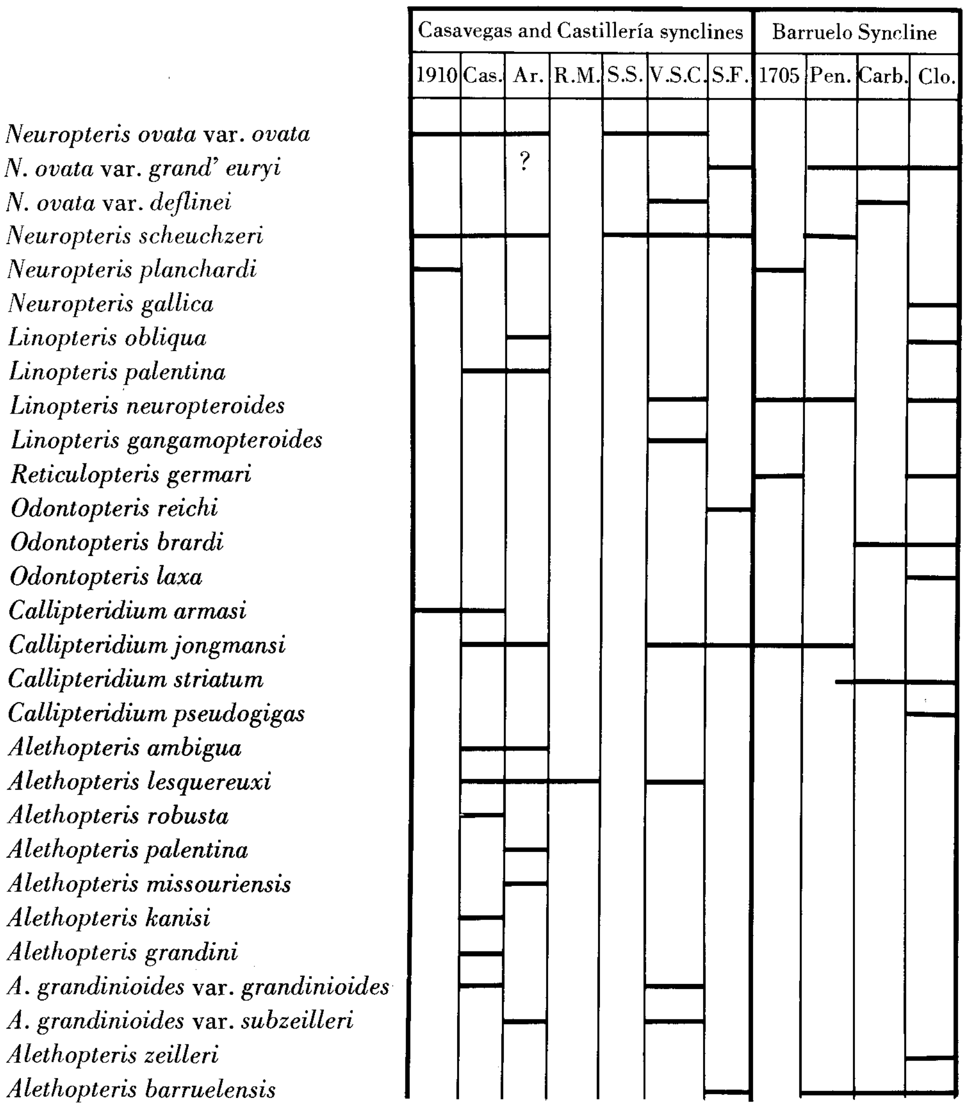
Throughout the post-Leonian succession in northern Palencia well preserved brachiopod faunas are found. These are being investigated by C. F. WINKLER PRINS (see the lists of brachiopods in the present paper and in WAGNER & WINKLER PRINS 1970), whose preliminary observations with regard to the age of the faunas in the Casavegas Syncline are quoted below (personal communication):

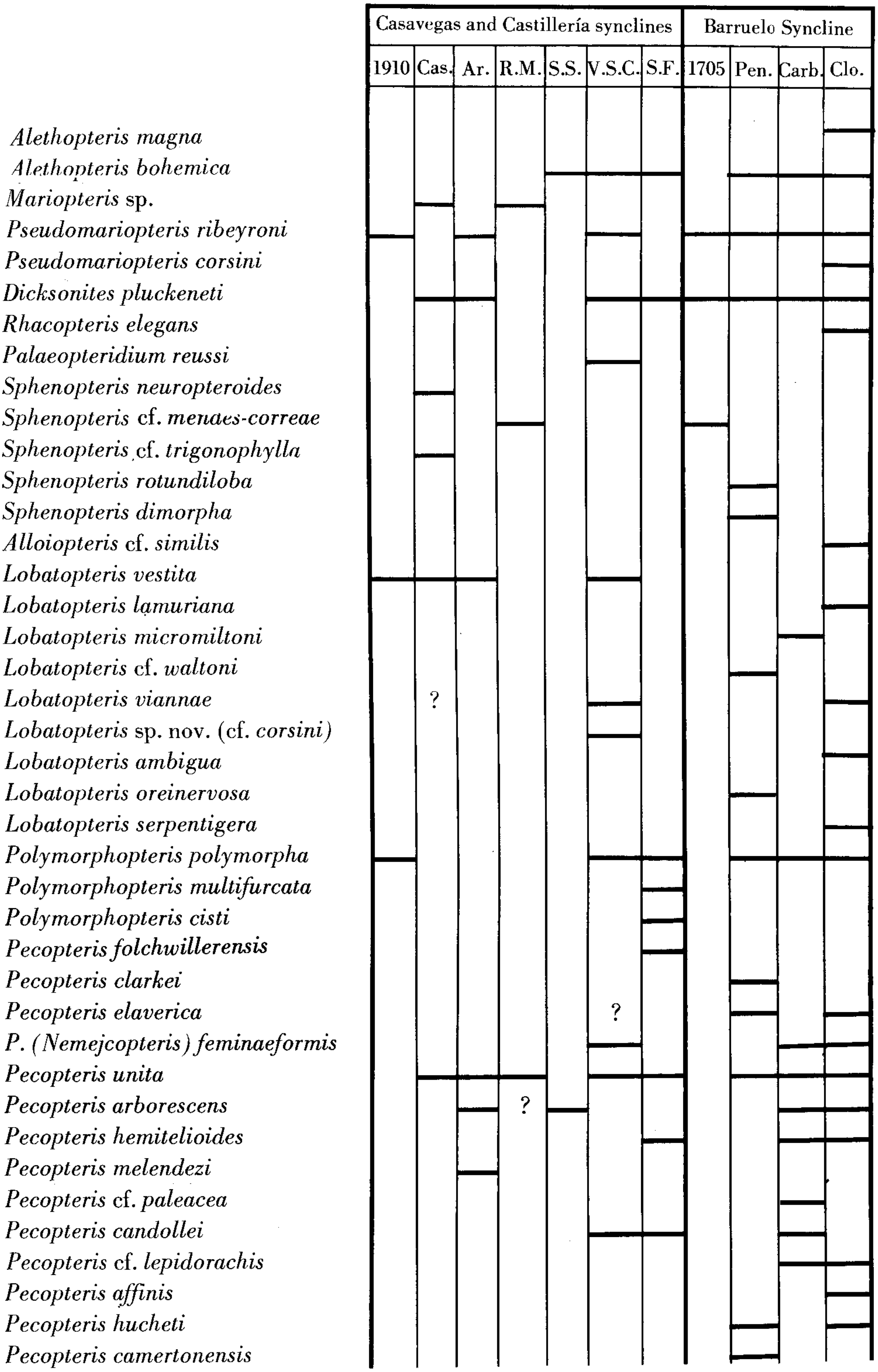
«The earliest brachiopod faunas in the post-Leonian succession of the Casavegas area (localities 1905 to 1907) should probably be assigned to the Myachkovian, the only later element in the fauna being *Attenuatella* aff. *frechi* (SCHELLWIEN). Above the upper Casavegas coals more of these younger elements appear, viz. *«Horridonia» incisa* (SCHELLWIEN), *Neochonetes latesinuatus miaokouensis* (CHAO), and *Alexenia* sp. ex gr. *reticulata* INANOVA. These species seem to indicate the Kasimovian (compare WAGNER & WINKLER PRINS 1970), and this faunal assemblage is found up to the level of the Peñacorba coals (text-fig. 11). It thus follows that the Myachkovian/Kasimovian boundary may be placed somewhat lower in the succession after the brachiopod faunas than it appears to be on the basis of the fusulinid assemblages studied by VAN GINKEL (1965). However, it should be noted that the brachiopods show essentially a combined Myachkovian/Kasimovian assemblage which may be difficult to separate. In the recent publications of SARYCHEVA (1968) and ABRAMOV (1970) no distinction is made between Myachkovian and Kasimovian assemblages. It may be that the appearance of certain species of Permian affinity as quoted for the assemblages above the upper Casavegas coals, indicate the Kasimovian rather than the Myachkovian, but it is possible that these appear already in the upper Myachkovian. The large and varied faunas collected in northern Palencia should be studied in more detail before this question can be solved».

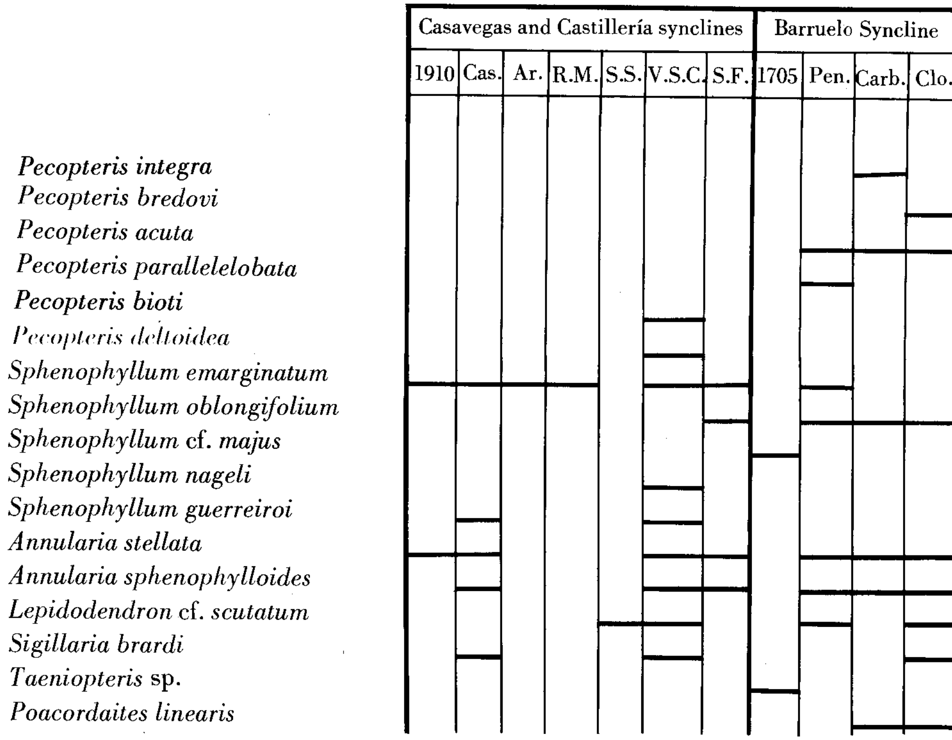
As a general conclusion it may be that the Myachkovian/Kasimovian boundary lies a little higher than, or coincides with the Westphalian D/Cantabrian boundary.

The Moscovian/Gzhelian boundary in Northwest Spain thus approximates to the Westphalian/Stephanian boundary and this appears to confirm the general correlation as given by GORSKY, STEPANOV *et al.* (1960). A more detailed correlation should be possible as soon as the faunas and floras collected in sequence in northern Palencia have been studied more completely.

Table I: Distribution of fossil flora in successive units of the *ca.* 5,000 metres of post-Leonian strata in northern Palencia, viz. the horizon of loc. 1910, Casavegas coals (Cas.), Areños coals (Ar.), Rosa María coals (R. M.), San Salvador coals (S. S.), Verdeña and San Cristóbal coals (V. S. C.), San Felices coals (S. F.) —all in the Casavegas and Castillería synclines—, and loc. 1705 of the Brañosera Formation, Peñacorba coals (Pen.), Carboneros (Carb.) and Calero coals (Clo.) in the Barruelo section (compare WAGNER 1964, Table III, and WAGNER & WINKLER PRINS 1970). The San Felices and Peñacorba coals are regarded as probably correlatable.




Casavegas and Castillería synclines
Barruelo Syncline
1910
Cas.
Ar.
R.M.
S.S.
V.S.C.
S.F.
1705
Pen.
Carb.
Clo.
Alethopteris magna
Alethopteris bohemica
Mariopteris sp.
Pseudomariopteris ribeyroni
Pseudomariopteris corsini
Dicksonites pluckeneti
Rhacopteris elegans
Palaeopteridium reussi
Sphenopteris neuropteroides
Sphenopteris cf. mendes-correae
Sphenopteris cf. trigonophylla
Sphenopteris rotundiloba
Sphenopteris dimorpha
Alloiopteris cf. similis
Lobatopteris vestita
Lobatopteris lamuriana
Lobatopteris micromiltoni
Lobatopteris cf. waltoni
Lobatopteris viannae
Lobatopteris sp. nov. (cf. corsini)
Lobatopteris ambigua
Lobatopteris oreinervosa
Lobatopteris serpentigera
Polymorphopteris polymorpha
Polymorphopteris multifurcata
Polymorphopteris cisti
Pecopteris folchwillerensis
Pecopteris clarkei
Pecopteris elaverica
P. (Nemejcopteris) feminaeformis
Pecopteris unita
Pecopteris arborescens
Pecopteris hemitelioides
Pecopteris melendezi
Pecopteris cf. paleacea
Pecopteris candollei
Pecopteris cf. lepidorachis
Pecopteris affinis
Pecopteris hucheti
Pecopteris camertonensis
?
?
?



CONCLUSIONS

1.—*Ca.* 5,000 metres of strata of upper Westphalian D to Stephanian A ages were deposited after the Leonian disconformity in northern Palencia. They constitute a continuous succession which can be divided into three large formations, viz. the Ojosa Fm., the Brañosera Fm. and the Barruelo Fm. Sedimentation commenced in small basin sags in the north-western part of the area studied and, locally, a special formation of fining upwards rhythmic units, the Rozo Formation, is developed at the base of the succession. The Ojosa formation, of the order of 2,400 metres thickness, is characterized by regressive rhythmic units (coarsening upwards sequences) which are basin fill successions after a sudden transgression. The Brañosera Formation is mainly characterized by turbiditic deposits, whilst the Barruelo Formation marks a return to basin fill sequences with a gradual increase of the non-marine component in the upper part of this formation. Strong folding of the Asturian Phase occurred after the Stephanian A as represented by the main part of the Barruelo Formation.

2.—Mapping and stratigraphic logging at the 1:100 scale in the Casavegas Syncline, in the north-western part of the general area, have elucidated the facies of the Rozo and Ojosa formations. The 94 metres of fine-grained, fining upwards rhythmic units of the Rozo Formation indicate an early transgressive phase punctuated by episodic uplifts of a more or less remote hinterland. Further downwarp of the basin took place during the deposition of the Ojosa Formation which represents repeated basin fill sequences. The sudden transgressions shown to have occurred at the base of each regressive rhythmic unit in the Ojosa Formation, may well have been due to movements along the line of the Los Llazos Fault which separated the basin from a foreland massif to the east. These movements may have been of the order of 20 m of downthrow along the fault line, thus deepening rather suddenly the adjacent basin and causing a withdrawal of the shoreline. The block east of the sedimentary basin only suffered a negligible amount of erosion (probably less than 100 metres) and remained remarkably stable during a long period of non-deposition which was equivalent to the time it took for the basin to accumulate over 2,000 metres of sediment. The actual depth of water in the basin was probably never in excess of some 50 metres and the regressive basin fills frequently built up to sea level with the subsequent formation of root beds and occasional coals.

3.—The fossil floras collected from non-marine and brackish intervals show the transition from upper Westphalian D to lowermost Stephanian. An arbitrary boundary for the basal lower Stephanian chronostratigraphic unit, the Cantabrian, has been suggested at the base of the Lores Limestone which is situated between the Casavegas coals, regarded as upper Westphalian D, and the Areños coals, considered to be lower Cantabrian in age. The Westphalian/Stephanian boundary approximates to the Moscovian/Gzhelian boundary which may, however, be a little higher in the succession, i.e. above the Areños coals. Dating in terms of the Russian chronostratigraphic sequence is based on fusulinid foraminifera (VAN GINKEL 1965), algae (RÁCZ 1966) and brachiopods (WINKLER PRINS, *in* WAGNER & WINKLER PRINS 1970 and this paper).

POSTSCRIPT

Since this paper was written the status of the Cantabrian Stage introduced by WAGNER (1966[a]) has been formalized by the decision of the I.U.G.S. Subcommission on Carboniferous Stratigraphy, at its meeting in Krefeld (August 1971), to recognize this stage as the lowest chronostratigraphic unit of the Stephanian Series, and to accept the sequence in the La Ojosa ridge as the stratotype of the lower part of this stage. The base of the Cantabrian Stage in its stratotype has been fixed as lying at the base of the Lores Limestone (compare BOUROZ *et al.*, in press, and GEORGE & WAGNER, in press).

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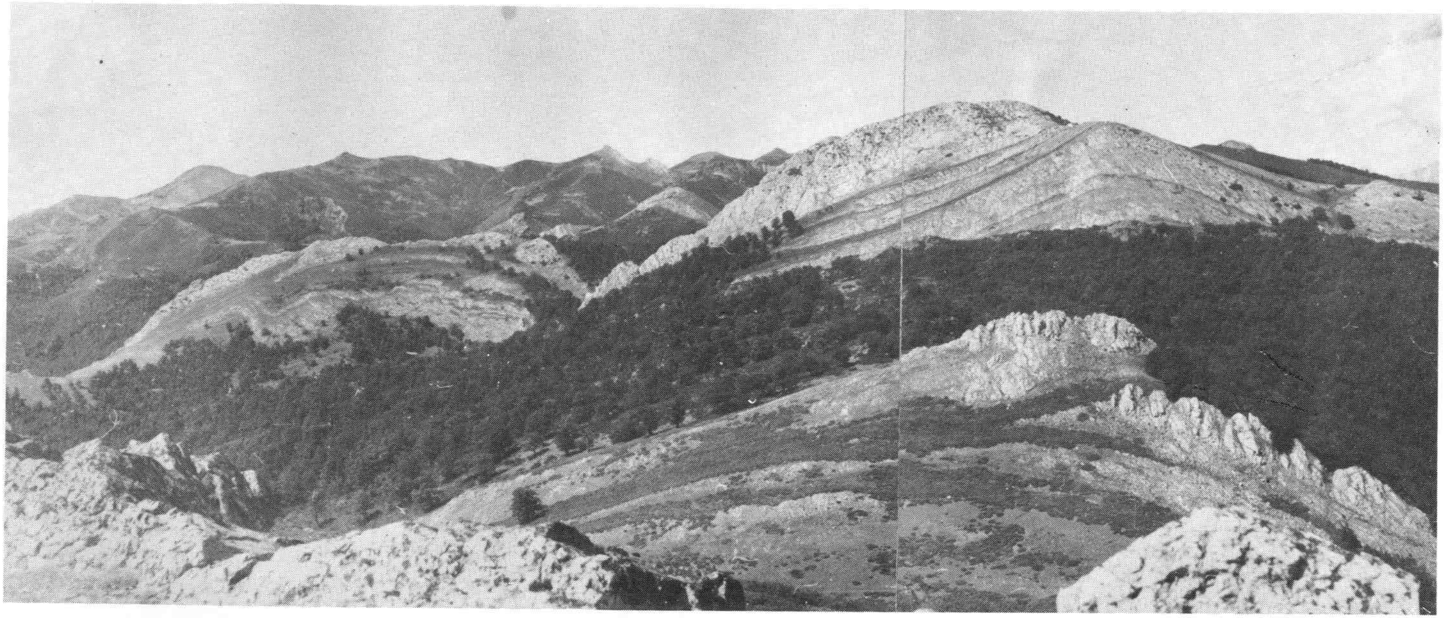
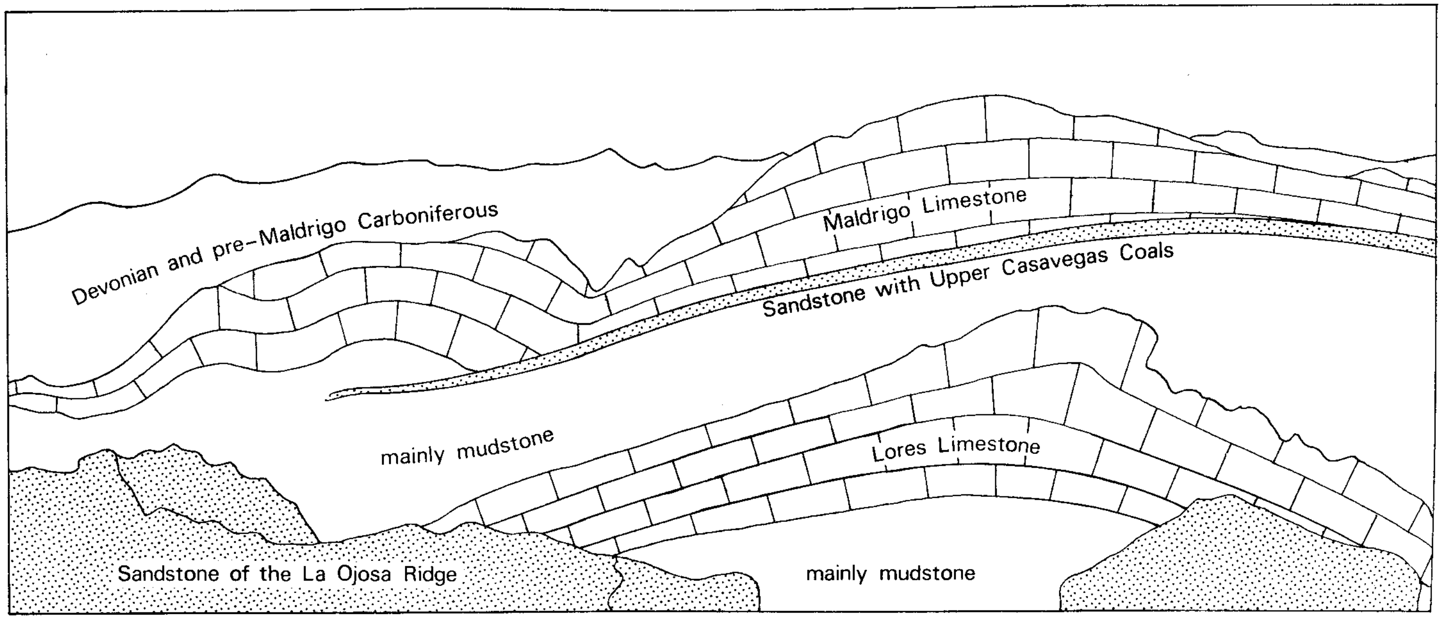
PLATES 1-2





A view of the La Ojosa ridge taken from a sandstone at the base of the Areños coal horizon and looking westwards. The prominent limestone in the background is the Maldrigo Limestone, of pre-Leonian Myachkovian age. Immediately in front of the Maldrigo Limestone is the sandstone ridge associated with the upper Casavegas coals. The limestone in the foreground is the Lores Limestone, of late Myachkovian age, which has been proposed as the basal unit of the Cantabrian succession in its stratotype. The col in the foreground, in a mudstone sequence, separates the village grounds of Lores (to the left) and Casavegas (to the right).

Fig. 1.—Steeply dipping sandstone belonging to the regressive rhythmic unit below that containing Areños coal 2 in the La Ojosa section, which has been investigated by trenching. The mountain in the background is formed by Devonian strata.

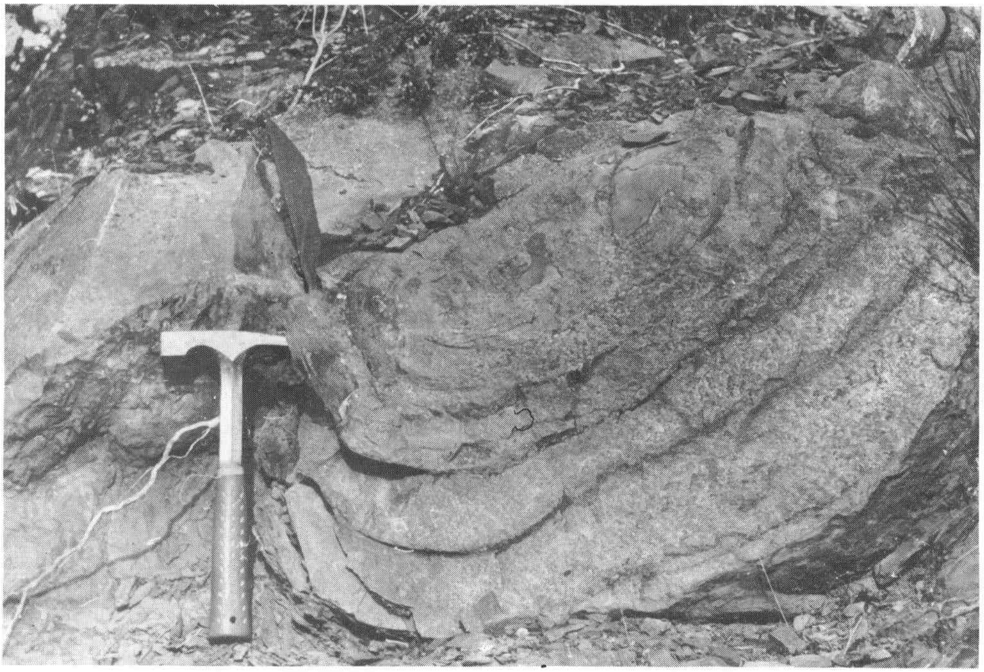


Fig. 2.—Ball and pillow structure in the Río Areños section (strata above the Areños coals). The shaft of the hammer is 28 cm long.