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LATE DEVONIAN AND EARLY CARBONIFEROUS PALAEOGEOGRAPHY OF SOUTHERN IRELAND AND SOUTHWEST BRITAIN

by

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(5 figures)

ABSTRACT. - During the Strunian and early Carboniferous, a marine transgression brought marine conditions progressively northward over the former Old Red Sandstone Continent in Britain and Ireland. The progress of the transgression is found to have been episodic, but the causes underlying the northward shift of the shore line are difficult to assess. Subsidence in the south of Ireland and in southwest England was very rapid, but there is a suggestion that some of the transgressive pulses, particularly those in the late Strunian, at the base of the Carboniferous and within the Middle Tournaisian, may have been caused by eustatic movements of sea level.

RESUME. - En Grande Bretagne et en Irlande, pendant le Strunien et le début du Carbonifère, une transgression amène progressivement des environnements marins vers le Nord où ils recouvrent le continent O.R.S. La transgression semble épisodique mais les causes sous-jacentes au déplacement vers le Nord de la ligne de rivage sont difficiles à mettre en évidence. Dans le Sud de l'Irlande et le Sud-Ouest de l'Angleterre, la subsidence a été très rapide mais il est suggéré que certaines des phases transgressives, en particulier celle du Strunien tardif, de la base du Carbonifère et du Tournaisien moyen, ont pu être provoquées par des mouvements eustatiques du niveau de la mer.

INTRODUCTION

Late Devonian and early Carboniferous rocks are widely distributed in southern Ireland, south Wales and southwest England. In the past fifteen years, many sections of this age in southern Ireland, both at outcrop and in borehole cores, have been the subject of sedimentological and biostratigraphical studies, so that it is now possible to reconstruct with some confidence the evolution of the palaeogeography of Ireland in the interval spanning the Devonian-Carboniferous boundary. The sections in south Wales and in southwest England have been less intensively studied, particularly from the point of view of biostratigraphy, and therefore the evolution of the palaeogeography of these areas is less well estabIshed.

During most of the Upper Devonian, Devon and Cornwall were part of a persistent marine basin, while to the north, in the Mendip Hills, around Bristol, in south Wales and in southern Ireland, continental Old Red Sandstone accumulated. During the latest Devonian and early Carboniferous, marine conditions became estabIshed over the southern part of this Old Red Sandstone Continent, and by early Viséan time, the coast line had moved, generally northward, into northern Ireland, northern England and Scotland.

The aim of this contribution is to present an analysis of the progress of the transgression in Britain and Ireland, in such a way that the data may be combined with information from other regions to assess the probability of widespread, or even global, stratigraphical and tectonic events around the time of the Devonian-Carboniferous boundary. It is possible to do this because of the development in Ireland of a refined biostratigraphical scheme based on miospores (Clayton *et al.*, 1974; Clayton & Higgs, 1979; Higgs *et al.*, 1986, in press) for the latest part of the Devonian and the earliest part of the Carboniferous. The first six biozones considered here (see below) each span a period of time unlikely to be more than 1 Ma in duration.

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In what follows, the biostratigraphical framework of our analysis is briefly described, and palaeogeographical maps for selected miospore biozones are presented with a brief commentary. We limit the geographical extent of our analysis to Ireland, Wales, the southwest of England and the west part of the English Midlands, because, although rocks of late Devonian and early Carboniferous age certainly occur in the sub-surface in southeast England, the amount of information available is not adequate to interpret the palaeogeographical evolution of that region. We do not include the Midland Valley of Scotland, where a succession of Upper Old Red Sandstone, in places several hundred metres thick, is followed conformably by marginal marine facies of late Courceyan (Tournaisian : Tn3c) age, because the Old Red Sandstone has so far not yielded microfloras. The dating of part of the Scottish succession as Upper Devonian on the basis of the fish faunas (Westoll, 1977) is, in our opinion, open to question; in any case, even accepting the assignments of age based on fish, the Devonian-Carboniferous boundary cannot be identified with sufficient accuracy or precision to allow the comparison of the geological history of the Midland Valley with that of other areas. The lack of reliable dates from the Scottish Upper Old Red Sandstone is unfortunate, because, as Bluck (1984) has pointed out, the sequences show evidence of important contemporaneous tectonic activity.

BIOSTRATIGRAPHICAL FRAMEWORK

Only miospores and, in the basinal successions, conodonts provide a sufficiently refined zonation to be useful in the sort of palaeogeographical analysis attempted here.

The sequence of miospore zones that we recognize (fig. 1) has evolved from the scheme proposed by Clayton *et al.* (1974). Full details of the new scheme are set out in Higgs *et al.* (1986, in press). Only the key taxa are shown in Figure 1 or are mentioned in the discussion below.

The oldest LL Biozone is identified by the presence of *Retispora lepidophyta* and the absence of *Hymenozonotriletes explanatus*. In Ireland its base coincides with the oldest occurrence of spore-bearing facies, except in one case (Higgs & Russell, 1980) where an older assemblage, possibly of the VCo Biozone, has been identified. Streel (1983) recognized two biozones in Belgium which probably equate with the LL

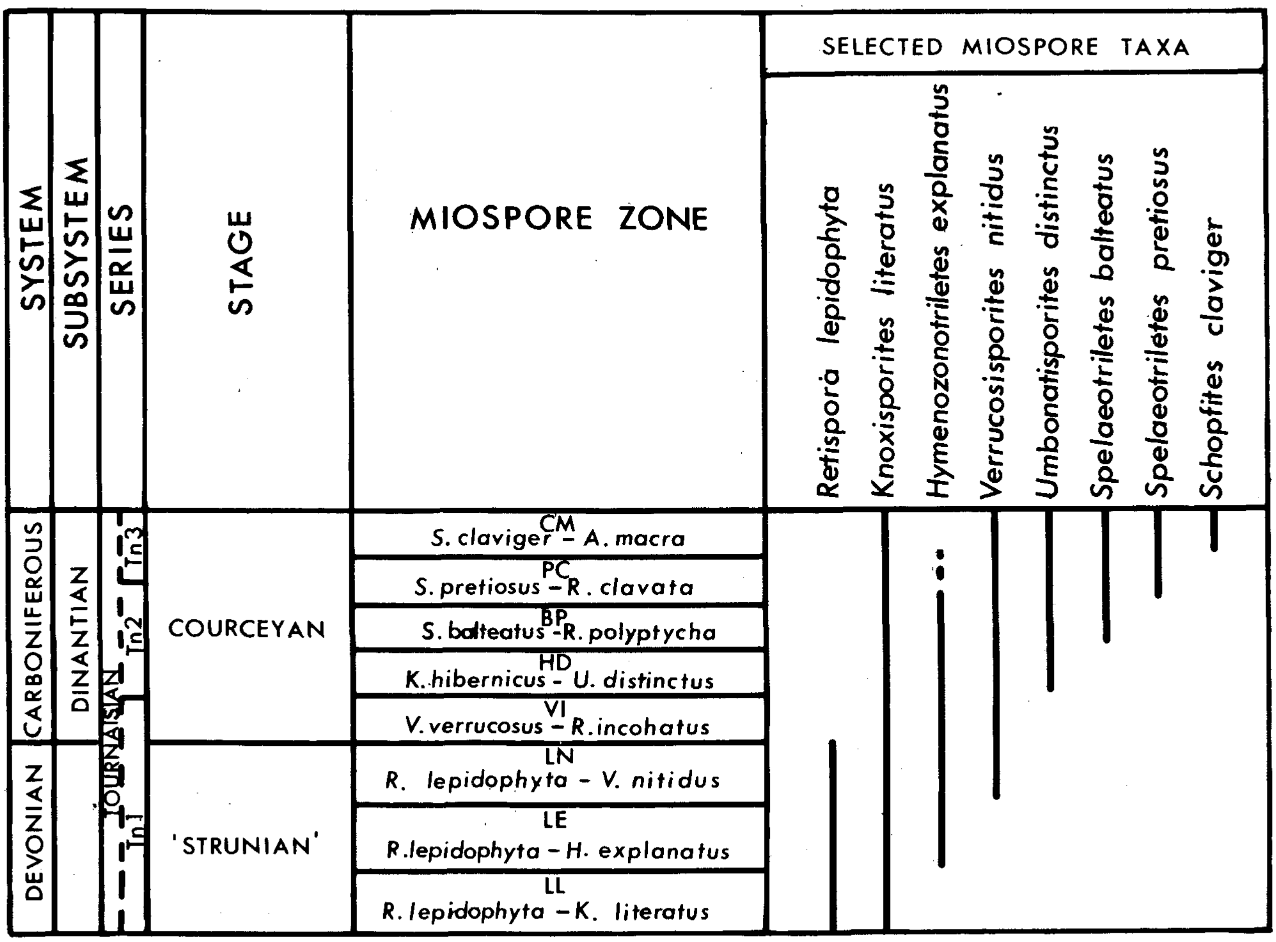

Figure 1. - The ranges of important miospore taxa within the Strunian and early Carboniferous.
Miospore Biozones from Higgs *et al.* (1986).

Biozone, as used here : the older LV Biozone is characterized by *R. lepidophyta* and the absence of *Knoxisporites literatus* (Streel, pers. comm. 1985) and occurs from the early (Fa2d) to the late (Tn1a) Strunian; the redefined LL Biozone is characterized by the common association of *R. lepidophyta* and *K. literatus* and has been found in the Tournai Borehole in a unit which Streel equates with the pre-Carboniferous part of the Hastière Limestone (Tn1bα). In Ireland, the occurrences of *Knoxisporites literatus* are too sporadic for us to recognize the LV Biozone; in our usage the LL Biozone probably corresponds to the LL and at least part of the LV Biozone of Belgium, and probably equates with part of Tn1a and Tn1b. In Germany, Higgs & Streel (1984) have recorded LL biozonal assemblages from below a *costatus* Zone conodont fauna. Previously described assemblages (Paproth & Streel, 1970) interpreted as belonging to the LL Biozone occur in the Hangenberg Schiefer within the *costatus* Zone.

The base of the LE Biozone is recognized by the first appearance of *Hymenozonotriletes explanatus*. This biozone has not been identified in Belgium, but has been shown by Higgs & Streel (1984) to equate with the Middle to Upper *costatus* Zone boundary in Germany.

Towards the top of the range of *R. lepidophyta*, *Verrucosisporites nitidus* appears; its first occurrence is used to identify the base of the LN Biozone. This biozone has not been recognized in Belgium. In Germany, LN Biozonal assemblages occur in the Hangenberg Schiefer at Stockum, immediately below the Stockum Limestone, which has yielded *Siphonodella praesulcata* and *Protognathodus kockeli* (Higgs & Streel, 1984).

The base of the VI Biozone is defined by the disappearance of *R. lepidophyta* and associated taxa. Numerous taxa typical of the late Devonian, such as *Rugospora flexuosa* and *Vallatisporites pusillites* also abruptly disappear at this level. Assemblages assigned to the VI Biozone are characterized by long ranging forms such as *Punctatisporites* spp., *Retusotriletes* spp. and *V. nitidus*. VI biozonal assemblages have been recognized in littoral facies of the Hastière Limestone (Tn1b) in the Bossuit borehole, north of Tournai, Belgium (Higgs & Streel, unpublished). The base of the Biozone has been identified at Hasselbachtal in the Hangenberg Schiefer, 14 cm below a horizon in the Hangenberg Kalk which has yielded *Siphonodella sulcata*.

The base of the HD Biozone is recognized by the entry of *Kraeuselisporites hibernicus* and *Umbonatisporites distinctus*. These taxa first occur at the base of the *peracuta* Shale (Tn2a) in the Bossuit borehole, near Tournai (Higgs & Streel, unpublished). A HD biozonal assemblage has been recovered from the base of the Liegende Alaunschiefer with a Lower *crenulata* Zone conodont fauna at Oberrödinghausen (Higgs & Streel, 1984).

The base of the BP Biozone is recognized by the entry of *Spelaeotriletes balteatus*. This biozone has not been recognized outside Britain and Ireland.

The base of the PC Biozone is recognized at the first occurrence of *Spelaeotriletes pretiosus*. Conodont faunas from just above this horizon in Ireland are of Upper *crenulata* Zone age and suggest a correlation with Tn2c of Belgium. The higher part of the Biozone is of post-*Siphonodella* Zone age (Clayton *et al.*, 1978).

In the basinal successions of Devon and Cornwall, most of the conodont zones described by Sandberg *et al.* (1978), which utilize the ranges of species of *Siphonodella*, can be recognized (Selwood *et al.*, 1982). In the facies of shallower water origin further to the north, zonal schemes based on conodonts do not allow detailed correlations.

PALAEOGEOGRAPHICAL MAPS

The palaeogeographical maps presented here are drawn on a base which is not palinspastically restored. Recent work (Isaac, 1985) has shown that some of the basinal successions of Devon and Cornwall are preserved in thrust sheets and nappes which have been transported northward for an unknown distance. There has been much argument about the degree of tectonic shortening further north in England, south Wales and Ireland : the debate centres on the relative importance of thrusting. In our opinion, it is unlikely that there has been northward transport on a scale comparable with that inferred for the Faille du Midi in Belgium. We conclude that the area transgressed by the sea around the time of the Devonian-Carboniferous boundary has been shortened by approximately 30 %. In areas further north the tectonic shortening was less.

Because of the relative amounts of data available, we first describe the palaeogeographical evolution of Ireland through late Devonian-early Carboniferous time before briefly commenting on the information from Wales and England.

IRELAND

Introduction

Upper Old Red Sandstone deposition in the south of Ireland began at least as early as the Middle-Upper Devonian boundary, when the Munster Basin (Graham, 1983) was initiated. The overall form of the basin is that of a half graben, with maximum subsidence of at least 6 km close to the northern fault-controlled margin. In the late Famennian or Strunian, the differential subsidence across the northern margin of the Munster Basin was reduced and a new region of maximum subsidence, the South Munster Basin, developed. Its northern margin is an approximately east-west line through Cork Harbour and the Kenmare Estuary (Fig. 2), south of which Strunian rocks are in places more than 800 m

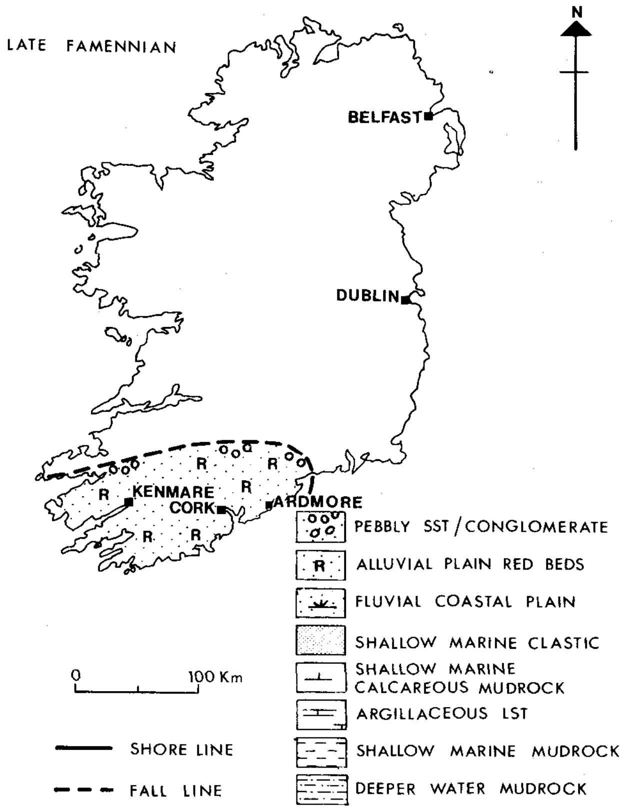

Figure 2
Outline palaeogeography of Ireland in the late Famennian.

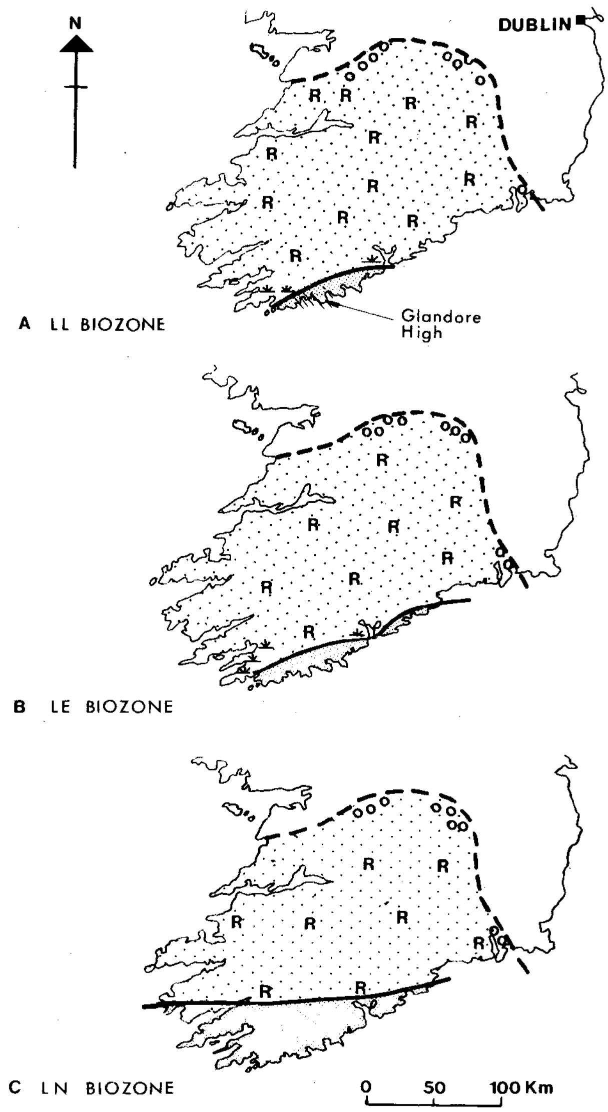

Figure 3. - Outline palaeogeography of Ireland during the LL Biozone (3A), the LE Biozone (3B), and the LN Biozone (3C). See Figure 2 for the key.

thick. Later, in the Carboniferous, this line was to become the southern margin of the carbonate shelf. The onset and progress of the late Devonian and early Carboniferous marine transgression must be viewed against this background of very rapid, tectonic subsidence.

The biostratigraphical data on which the palaeogeographical maps are based are summarized in Higgs *et al.* (1986, in press). Sedimentological data are drawn mostly from the publications cited by Higgs *et al.* The reader is referred to previous, more extensive syntheses of stratigraphical and sedimentological data by Gardiner & MacCarthy (1981), Graham (1983), Naylor *et al* (1983) and Sevastopulo (1981).

Famennian (Figure 2)

It is impossible to provide more than an extremely generalized map for this interval because of the lack of biostratigraphical control. Figure 2 shows a speculative palaeogeography for the time during which the upper part of the Castlehaven Formation (Graham, 1975) was being deposited in south County Cork. At this time, the Munster Basin was a broad alluvial plain traversed by rivers flowing generally from the north. Coarse alluvial fan deposits were restricted to the northern margin of the basin and the more southerly areas received only medium grained sand, silt and mud. There is no evidence for any marine influence in rocks of this age in the part of the basin preserved onshore in southern Ireland. The position of the shoreline of the marine area to the south, into which the rivers of the Munster Basin drained, is not known.

LL Biozone (Figure 3A)

In south County Cork, the Castlehaven Formation and other age-equivalent red bed sequences are overlain conformably by the Toe Head Formation, which consists of dominantly grey and green sandstone and mudrock, interpreted by Graham (1975) as originating on a coastal plain. The Toe Head Formation is overlain conformably by the Old Head Sandstone Formation, which was deposited in shallow, marine, tidally influenced environments (Graham, 1975). Along the south coast of County Cork, the base of the Old Head Sandstone, and thus the marine transgression, occurs in the LL Biozone. Slightly further to the north and west, the LL Biozone has been identified in facies equivalent to the Toe Head Formation, and the earliest marine deposits are younger. North of Cork, rocks of LL Biozone age are in fluviatile red bed facies, that are fine grained in the south but notably pebbly close to the fall line, which by this time had migrated from its position in the Famennian northward across the margin of the Munster Basin.

The great thickness of shallow water marine sediment (in places more than 200 m) that accumulated in south County Cork during the LL Biozone is evidence that basin subsidence continued apace. However the initial incursion of the sea resulted in a shore line that more or less parallels the south coast and is not deflected, as far as is known, by a persistent area of reduced accumulation of sediment, which has been termed the Glandore High (Fig. 2A; see also the isopachs for the Old Head Formation shown by Naylor *et al.*, 1983, Fig. 2.6). This suggests that the transgression was caused either by an eustatic rise in sea level or by regional tectonic subsidence which affected the whole of the south Cork area.

LE Biozone (Figure 3B)

During this Biozone, marine conditions spread slightly further to the northeast, but there was negligible movement of the shore line in a northwest direction. Although the data are sparse there is no evidence of northward migration of the margin of Old Red Sandstone deposition. The maintenance of a static shoreline through this interval of time, during which more than 200 metres of shallow water marine sandstones accumulated, required rapid subsidence closely balanced by rapid supply of sediment, and suggests the presence of a persistent tectonic hinge.

LN Biozone (Figure 3C)

It seems probable that the LN Biozone is equivalent to a short period of time because in most areas (outside the South Munster Basin) it is represented by very small thicknesses of rock. In the southern part of the Basin, it is identified in the upper part of the Old Head Sandstone Formation, which is commonly coarser grained than at lower horizons. In a general way this reflects the northward migration of high energy shoreface (barrier) sands over inshore sands and muds. Despite the limited duration of the Biozone, there was a substantial movement of the shore line, both in terms of distance and orientation : in the west it migrated to the head of the Kenmare Estuary (Higgs & Russell, 1981) and became nearly east west, thus paralleling the margin of the South Munster Basin. It is difficult to assess the relative contributions of local subsidence and more widespread sea level rise to this transgression. Certainly in the south part of the South Munster Basin, the thickness of the LN Biozone (in places more than 250 m) requires rapid subsidence,

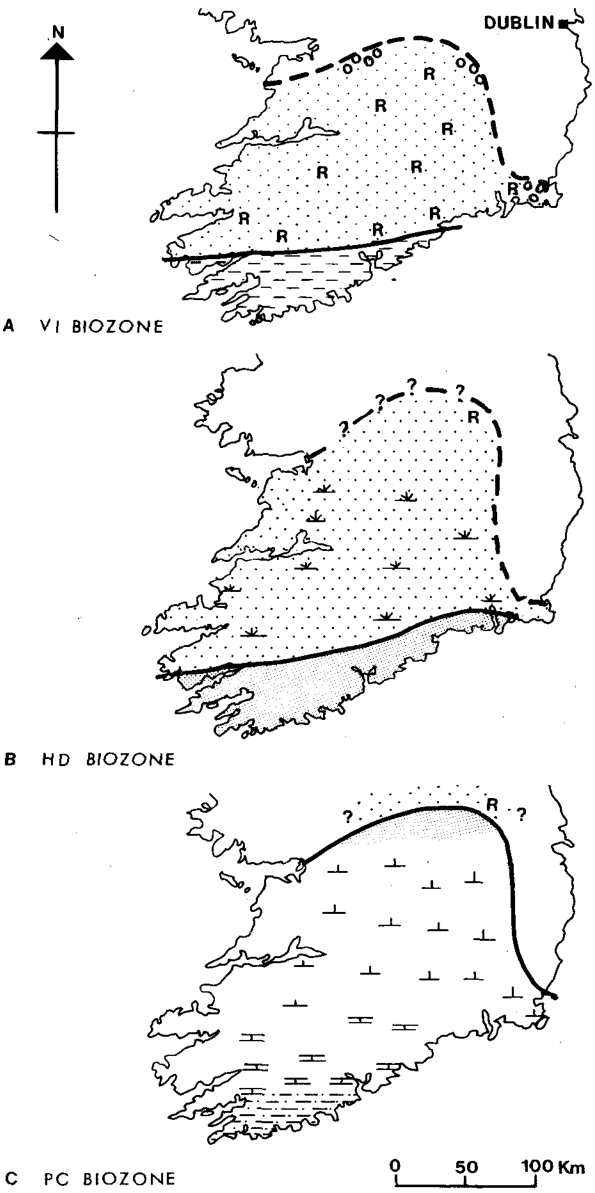

Figure 4. - Outline palaeogeography of Ireland at the base of the VI Biozone (4A), during the HD Biozone (4B), and early in the PC Biozone (4C). See Figure 2 for the key.

and the change in orientation of the shore line also suggests underlying structural control.

VI Biozone (Figure 4A)

The base of the VI Biozone in south County Cork coincides with a marked change of facies : the generally coarse sandstone of the upper part of the Old Head Sandstone Formation is overlain by the Castle Slate Member of the Kinsale Formation, a dark grey mudrock with a restricted fauna of cephalopods, small crinoids, conodonts and ostracodes. The Castle Slate has been recognized from as far north as the south side of the Kenmare Estuary to the Ardmore area, in both cases only a small distance south of fluviatile red bed facies of the same age. In the Kenmare Estuary, according to Van der Zwan & Van Veen (1978), the Castle Slate spans the LN/VI Biozone boundary. Occurrences of the Castle Slate within the LN Biozone are anomalous, and these reports require re-investigation (similar reports in the Cork Harbour region (Sleeman *et al.*, 1978) have been found to have resulted from misidentification of the base of the Member).

The radical change of facies over so large an area is most easily explained by a relative rise in sea level, which altered the base level of the rivers draining the land area to the north, so that sand, instead of being transported into the shallow sea in County Cork, was deposited on the coastal plain further north, and only the fines reached the marine basin. The near-isochronous base of the Castle Slate, from which we infer a very rapid spread of the mud facies over the area of former shallow water sandstone deposition, is most easily explained as the result of a rapid eustatic rise of sea level. Such a rise, however, would have been relatively small (perhaps 10 metres or less); a greater rise would have inundated a large area to the north, given the probable very low gradients of the coastal plain. Although the Castle Slate with its fauna of cephalopods (Matthew 1983) superficially resembles the deep water, goniatite-bearing mudrock facies known in several places in the Variscan rocks of Europe, its origin was in shallow water as borne out by the conodont fauna, which contains shallow water taxa such as *Patrognathus* and lacks siphonodellids, and by its gradational passage upward into shallow water sandstones.

HD Biozone (Figure 4B)

In the South Munster Basin, the HD Biozone is found within the upper part of the Kinsale Formation which consists of sandstone and mudrock of shallow marine origin. Rapid subsidence of the basin continued. North of the basin margin there was a slight shift in the shore line, but the most significant change in the palaeoenvironment was the replacement of the alluvial plain red bed facies by dominantly grey and green sandstone and mudrock. The sedimentology and age of this association of facies is currently under investigation. Preliminary interpretations suggest that it represents mainly coastal plain facies, as shown in Figure 4B, which depicts the palaeogeography for an horizon in the lower part of the Biozone; but it may also include some shallow marine sandstone (particularly at higher horizons), which would lead to the shore line being drawn further to the north. The position of the fall line at this time is speculative, but is unlikely to be much further north than shown in Figure 4B.

PC Biozone (Figure 4C)

The BP Biozone probably represents a very short interval of time. A palaeogeographical map for the Biozone, based on the relatively sparse information available, is very similar to that for the HD Biozone (Figure 4B) with perhaps a moderate northward shift of the shore line.

During the PC Biozone there was a profound change in the palaeoenvironments and palaeogeography. In the earliest part of the Biozone (at an horizon older than that on which Figure 4C is based) shallow water sandstone and mudrock of the Kinsale Formation continued to accumulate in the South Munster Basin, but the coastal plain of the region to the north shown in Figure 4B, became a marine shelf, where mixed shallow water carbonates (mainly in the south) and clastic sediments were deposited. The sedimentary sequences on the shelf (Sevastopulo, 1981) are interpreted as reflecting initial deepening during a transgressive phase followed by aggradation and shallowing. In many areas the upper part of these sequences show clear signs of emergence in the widespread development of mud cracked flaser- and linsen-bedded sandstone and mudrock. Both in the South Munster Basin and on the shelf to the north, the sandy facies are abruptly followed by almost sand free, variably calcareous mudrocks with diverse, open marine, faunas including siphonodellid conodonts, which first appear at this level in Ireland. The lowest beds of the mudrock facies contain phosphate nodules and phosphatised fossils, and are interpreted as lag deposits at the base of a large scale marine transgression. The map in Figure 4C is drawn for a time shortly after the transgression had taken place, in the lower part of the PC Biozone. The transgression within the HD Biozone may have been gradual, but that within the lower part of the PC Biozone appears to be so rapid and widespread, that it is most easily explained as having resulted from an eustatic rise in sea level or from rapid regional subsidence or tilting.

ENGLAND AND WALES

The positions of the shore line in the late Devonian and early Carboniferous in England and Wales are shown in Figure 5, together with the localities from which the more important biostratigraphical data have been obtained.

In south Devon and Cornwall, the late Devonian and early Carboniferous, in both basin and rise facies, have been identified in imbricate thrust sheets that have been transported from the south (Selwood *et al.*, 1985). Selwood *et al.* (1982) have described a borehole section of this age at Chillaton (locality 1 in Figure 5). They recorded a thin succession of pale grey micaceous slates ranging from the *costatus* Zone to the Lower *crenulata* Zone, followed by dark grey to black, siliceous mudrock of Lower *crenulata* Zone age. The *isosticha* Upper *crenulata* Zone is represented by siltstones, which contain silicified clasts, and tuffs, pointing to a dynamic phase of sedimentation in the basin, which elsewhere is manifested in the deposition of flysch and the generation of olistostromes. The faunas are closely akin to those from Germany : *costatus* Zone conodonts in-

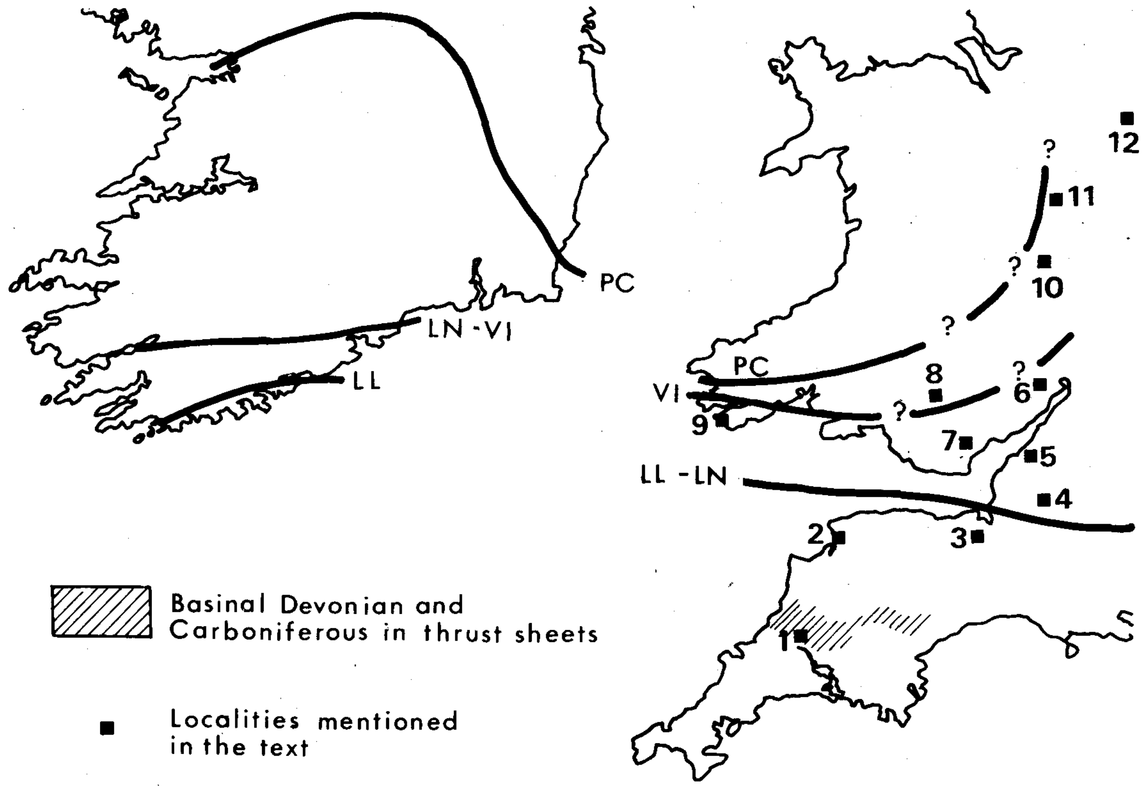

Figure 5. - Successive positions of the shore line during the time between the Strunian (LL Biozone) and the early Carboniferous (PC Biozone).

cluding *Siphonodella praesulcata,* occur with phacopid and proetid trilobites, and the entomozoid ostracodes *Richterina costata* and *Richterina striatula.* Less than 0.15 m above the highest occurrence of phacopid trilobites is a bed containing *Drevermannia moravica minuta,* a trilobite which indicates an earliest Carboniferous age. *Siphonodella sulcata* was recorded from an horizon 0.15 m higher.

In north Devon (Locality 2 in Figure 5) the late Devonian and early Carboniferous succession records a transition from continental environments (Pickwell Down Sandstone), through possible intertidal facies (Upcott Beds), shoreline and inshore marine deposits (Baggy Sandstones), to offshore neritic environments (Pilton Shales) (Goldring *et al.,* 1978). Dolby (1970) recorded a miospore assemblage from the base of the Baggy Sandstones which is assigned by us to the LL Biozone. An assemblage from the base of the Pilton Shales is referred to the LE Biozone. Goldring (1970) correlated the Devonian-Carboniferous boundary with an horizon within the Pilton Shales. The rate of subsidence in north Devon was substantial (approximately 800 m of shallow marine sediments were deposited between LL Biozone times and the Devonian-Carboniferous boundary) but the biostratigraphic data are not adequate to establish whether the major facies changes within this generally transgressive sequence correlate with the movements of the strand line recognized in Ireland.

The Knap Farm borehole at Cannington Park, Somerset (Locality 3 in Figure 5) was drilled at the southern margin of the Dinantian carbonate shelf (Whittaker & Scrivener, 1982; Mitchell *et al.,* 1982). The Coy Sandstone at the bottom of the borehole is marine since it contains acritarchs and conodonts (assigned to the *costatus* Zone). It has yielded miospore assemblages assigned here to the LL Biozone; *H. explanatus* has not been recorded, so the LE Biozone may be missing. An assemblage assigned to the LN Biozone occurs within the lower 2 m of the shallow marine Lower Limestone Shales, which rest, apparently disconformably, on the Coy Sandstone. Younger horizons within the Lower Limestone Shales have provided miospore assemblages assigned to the VI Biozone.

Dolby (1970) recorded miospore assemblages from the Portishead Beds (Old Red Sandstone) and the shallow marine Lower Limestone Shales at Burrington Combe (Locality 4 in Figure 5). The assemblages from the Portishead Beds are assigned here to the LL, LE and LN Biozones, the latter Biozonal assemblage occurring 8 metres below the top of the formation. Assemblages from the lower beds of the Lower Limestone Shales are assigned to the VI Biozone. In this area, the marine transgression took place very close to the Devonian-Carboniferous boundary.

In the Avon Gorge (Locality 5 in Figure 5), Utting & Neves (1970) recorded a LL biozonal assemblage from approximately 25 m below the top of the nonmarine Portishead Beds. The onset of marginal marine conditions in the overlying Shirehampton Beds cannot be dated accurately but miospore assemblages from the middle of the formation are here assigned to the VI Biozone.

At Westangle Bay, Dyfed (Locality 9 in Figure 5), miospore assemblages recorded by Dolby (1970) and Bassett & Jenkins (1977) from the top of the Skrinkle Sandstone (Marshall, 1978) suggest that, as at Burrington Combe, the marine transgression occurred close to the base of the VI Biozone.

Elsewhere in Wales and the Welsh Borderland, biostratigraphic data are sparse. Gayer *et al.* (1973) have recorded miospores assigned to the LL Biozone from an horizon approximately 20 m below the top of the Old Red Sandstone in the Taff Gorge area (Locality 7 in Figure 5). According to information in Lovell (1978), the base of the marine Lower Limestone Shales on the north crop of the south Wales Coalfield (Locality 8 in Figure 5) is likely to be younger than the VI Biozone. Sullivan (1964) recorded a miospore assemblage assigned here to the BP Biozone from the marine Lower Limestone Shales in the Forest of Dean (Locality 6 in Figure 5). Further north at Titterstone Clee and Lilleshall, Shropshire (Localities 10 and 11 in Figure 5), there is strong evidence that deposits equivalent in age to the lower part of the PC Biozone are in marine facies (Mitchell & Reynolds, 1981). The Caldon Low borehole (Locality 12 in Figure 5) encountered Old Red Sandstone facies Rue Hill Sandstones conformably overlain by the Rue Hill Dolomites, which consist of dolomites, breccias and mudstones (Welsh & Owen, 1983). A miospore assemblage from the base of the Rue Hill Dolomites is here assigned to the HD Biozone. PC biozonal assemblages have been recorded from slightly higher in the formation.

CONCLUSIONS

1. From the Strunian (LL Biozone) to the Middle Tournaisian (PC Biozone) there was a progressive marine transgression over the Old Red Sandstone Continent in Britain and Ireland.
2. Subsidence in the south of Ireland and southwest England was very rapid; as a result the Strunian and early Carboniferous successions are very thick.
3. Despite the high rate of subsidence, the transgression northward appears to have been episodic, with relatively long periods when the shoreline remained static, interspersed between times of rapid migration.
4. It is difficult to separate the relative contributions of regional subsidence and of eustatic rise of sea level to the progress of the transgression; possible cases of eustatic sea level changes in the LL Biozone, at the base of the VI Biozone and within the early part of the PC Biozone need to be assessed by comparisons with data from other parts of Europe and from other continents.

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