THE MID - DINANTIAN STRATIGRAPHY

OF

PEMBROKESHIRE

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I. INTRODUCTION

1. Geological Setting

The Lower Carboniferous rocks of Pembrokeshire, described in several memoirs of the Geological Survey, have long been known to lie along the Armorican front in South Wales. They show marked variations both in lithology and in thickness as they are traced northwards from the southern to the northern outcrops - a variation that may be looked upon as reflecting incipient stages of Armorican movements. It is a main purpose of the present thesis to examine, in detail, the stratigraphical evidence provided by the mid-Dinantian rocks of the depositional and palaeogeographical environments in which these variations occurred.

The rocks, as Dixon fully showed, are preserved in a number of isolated synclines that occupy much of Southern Pembrokeshire and they are described in the N.S. one-inch Geological Survey Sheets 244, 245 and 228 and parts of 229, 226-227 (see fig.2). To the north lies the Pembrokeshire Coalfield, the northern margin of which, from Haverfordwest to Pendine, is limited by the outcrop of Millstone Grit and Carboniferous Limestone,

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Fig. 1 Outline map showing the position of Pembrokeshire in the S.W. Province.

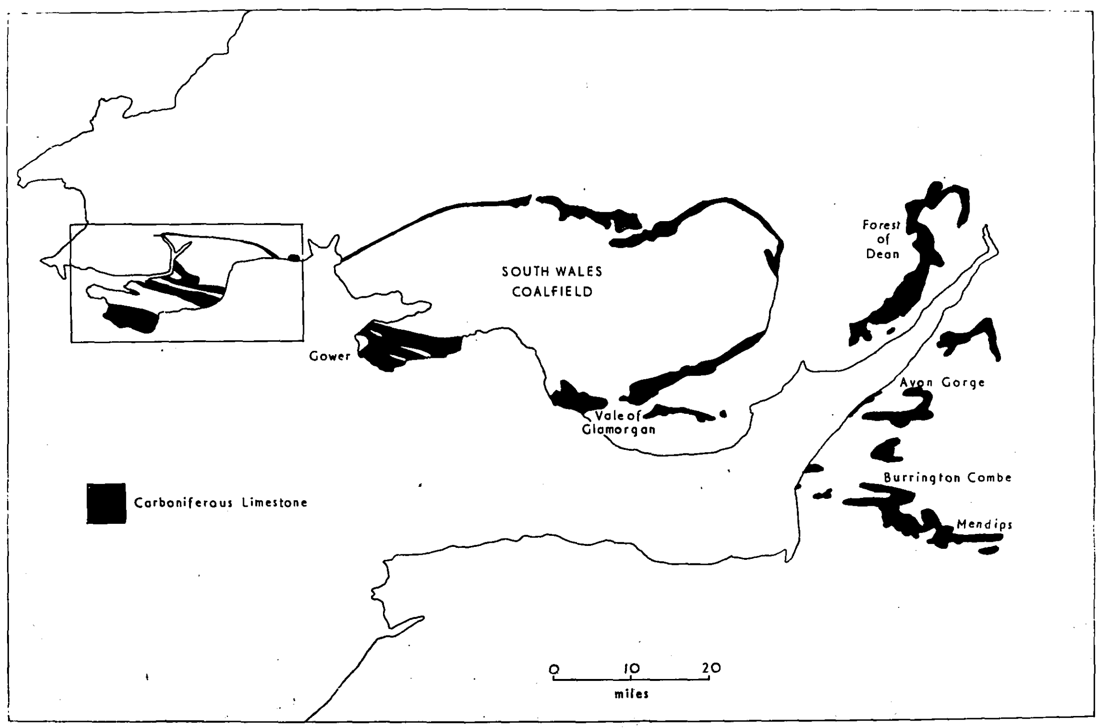
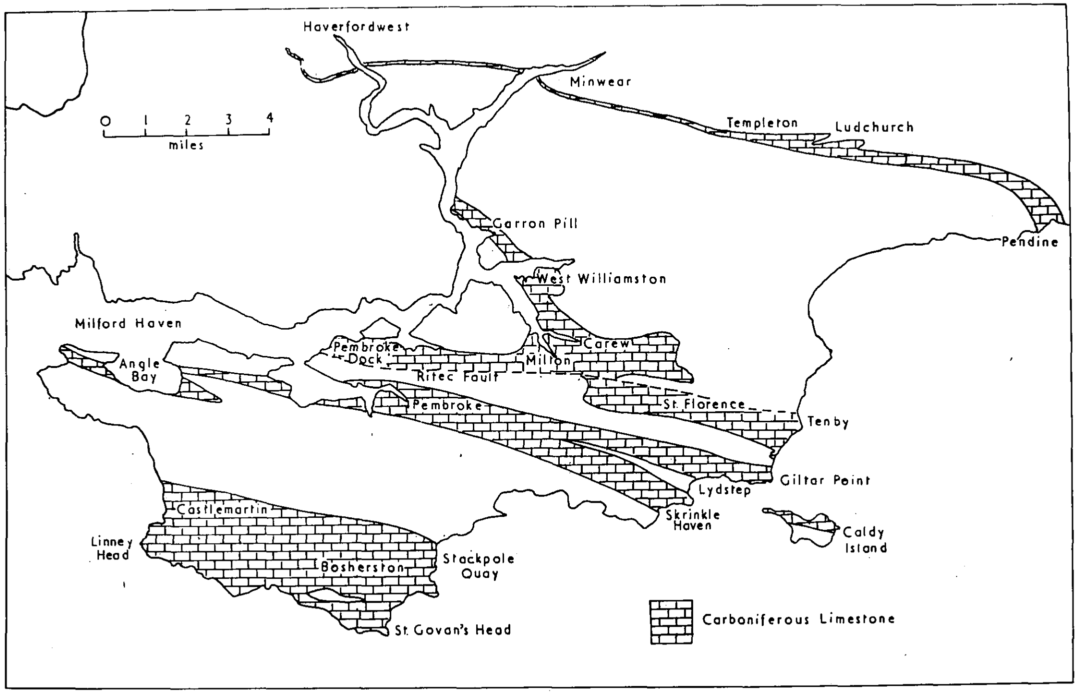

SOUTH WALES
COALFIELD
Forest
of
Dean
Gower
Vale of
Glamorgan
Avon Gorge
Burrington Combe
Mendips
Carboniferous Limestone
0
10
20
miles

Fig. 2 Outline map showing the outcrops of the Carboniferous Limestone in Pembrokeshire.


Haverfordwest
Minwear
0 1 2 3 4
miles
Templeton
Ludchurch
Carron Pill
Pendine
West Williamston
Milford Haven
Angle Bay
Pembroke Dock
Carew
Milton
Ritec Fault
St. Florence
Tenby
Pembroke
Giltar Point
Lydstep
Skrinkle Haven
Caldy Island
Castlemartin
Linney Head
Bosherston
Stackpole Quay
St. Govan's Head
Carboniferous Limestone

while the southern margin over the greater part is faulted. Southwards the Carboniferous Limestone is repeated in a series of east-west synclines having on the whole an easterly pitch. Old Red Sandstone and Silurian rocks outcrop along the crests of the complementary anticlines.

From north to south the outcrops of Carboniferous Limestone are :

(a) The Haverfordwest-Pendine outcrop along the North Crop of the Pembrokeshire Coalfield.

(b) The West Williamston-Pembroke Dock outcrop to the south of the Coalfield along the Burton Anticline. The outcrop is terminated to the south by the Ritec Fault.

(c) The Tenby-St. Florence Syncline between the two major structures of the Ritec Fault and the Ridgeway Anticline.

(d) The Pembroke Syncline bounded on its southern side by the compound Orielton Anticline which brings Old Red Sandstone and Silurian to the surface. In the west, the southern limb has a pronounced "buckle", the Angle Syncline, in /

which only lower Tournaisian rocks are preserved.

(e) The Bosherston outcrop in the extreme south, the dominant structure being the Bullslaughter Bay Syncline. Along the coast from Stackpole Quay to Freshwater West a complete and thick succession of Carboniferous Limestone is well exposed.

2. The Application of the Dinantian Stages by Dixon to Pembrokeshire

The history of research in Pembrokeshire has been reviewed by Leach (1933 pp.190-192).

During the first decade of this century the Geological Survey extended its revision of the South Wales Coalfield to Pembrokeshire. The period was one of major advances in Carboniferous stratigraphy with the establishment by Vaughan (1905) of the coral and brachiopod zones in the Bristol district. Dixon applied the zonal scheme to Pembrokeshire, his work being published in the Haverfordwest (1914) and the Pembroke and Tenby (1921) Memoirs - the later after several years' delay caused by war.

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The nomenclature of Vaughan's zonal scheme has been modified in the light of continuing research, and it is first necessary to equate the terms used by the author in the present account with those employed by Dixon in the subdivision of the Carboniferous Limestone of Pembrokeshire.

		Dixon's Scheme	As herein defined
AVONIAN	UPPER	Dibunophyllum Zone (D)	Dibunophyllum Zone (D)
		Upper Seminula subzone (S_2)	Seminula Zone (S_2)
		Lower Seminula subzone (S_1) }	Upper Caninia Zone (C_2S_1)
		Upper Syringothyris subzone (C_2) }	
	LOWER	Lower Syringothyris subzone (C_1)	Lower Caninia Zone (C_1)
		Zaphrentis Zone (Z)	Zaphrentis Zone (Z)
		Cleistopora Zone (K)	Cleistopora Zone (K)

To accord with modern practice, the terms Tournaisian and Viséan are used in place of Lower and Upper Avonian.

The faunal zones adopted by Dixon were essentially similar to those defined by Vaughan, but he modified the zonal scheme and introduced new interpretations into Dinantian stratigraphy. The most important modification was the division into the Upper and Lower Avonian. The boundary between them was drawn

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by Vaughan, on palaeontological grounds, in the lower part of the Upper Caninia Zone. Dixon, on the other hand, suggested that the boundary should be placed at the base of the Upper Caninia Zone below the junction advocated by Vaughan. Dixon drew this boundary at the top of the Caninia Oolite or its equivalent horizon. The junction represented a sharp lithological and faunal change which was emphasized by commencement of a widespread marine transgression and the local development of unconformity.

Dixon's conception of the faunal zones was fundamentally different from that of Vaughan's. The latter originally considered his zonal groupings represented a series of continually evolving "gentes". Dixon, on the other hand, considered that the stages and zones were purely artificial, and the divisions between them were conveniently drawn at lithological boundaries. He emphasized the importance of relating changes in fossil assemblages to changes in sedimentation, which in their turn reflected the influence of earthmovements. It was on this basis that the modifications of Vaughan's zones were undertaken and applied to Pembrokeshire.

Northwards from the "standard" development of the Tenby and Pembroke outcrops the Dinantian zones were shown to thin, partly because of the increased affect of the mid-Dinantian movements and partly as a result of nearness to the fluctuating Dinantian shore-line. The succession at West Williamston was comparable in many respects to the Tenby-St.Florence Syncline except for the evidence of erosion in the middle of the _Caninia_ Zone and the development of oolites in the Upper _Caninia_ Zone, instead of "standard" bioclastic limestones, which could not be separated from the _Seminula_ Zone above. The emergence at West Williamston was thought to be brief, it was merely the clearest manifestation of earthmovements which affected the whole of S.W. Province. It was, Dixon considered, reflected in progressive shallowing of the Tournaisian sea indicated by the incoming of _Laminosa_ Dolomite and _Caninia_ Oolite. Along the

North Crop of the Pembrokeshire Coalfield, the movements were shown to have their maximum expression and much of the Lower Avonian was shown to be absent by erosion.

In these areas the division between the two stages was readily defined by Dixon. However, southwards from the Pembroke Syncline the mid-Dinantian movements were no longer strongly felt. The Caninia Oolite was seen to be absent and the major part of the Tournaisian and Upper Caninia Zone in the Bosherston outcrop was represented by a thick succession of "zaphrentid phase" limestones in Dixon's sense (1921 p.72), that is, thinly bedded, dark bioclastic limestones with interbedded mudstones and shales with abundant small solitary corals. The fauna in this uniform deposit showed that Vaughan's confidence in certain zonal index fossils had been misplaced. The fauna throughout the sequence had, at first sight, a typically Tournaisian aspect. However, Dixon utilized the incoming of new forms and slight lithological changes reflecting the mid-Dinantian movements to apply his divisions. The only marked lithological change in over 2,500 feet of "zaphrentid phase" limestone was the development of reef dolomite in the middle of the succession, the reef being "shallow-water" like the Caninia Oolite elsewhere. It was at the top of the reef dolomite that Dixon drew the boundary between the Lower and Upper Avonian. The evidence for including the reef in the Lower Caninia Zone, in the absence of fossils due to dolomitization, was the occurrence of Upper Avonian forms above and forms referred to Horizon γ below (Dixon 1921 p.129). In addition, Dixon compared the development with the Waulsortian Reefs in Belguim, Clitheroe and County Clare, also supposedly in part of Tournaisian age.

Dixon's classic synthesis of the Dinantian in Pembrokeshire resulted in a considerable clarification of Lower Carboniferous stratigraphy in the S.W. Province. The development at Pendine and West Williamston was comparable with that of the North Crop of the South Wales Coalfield, while that at Tenby corresponded with /

S.E. Gower and Bristol, and the Pembroke area to S.W. Gower. The Bosherston outcrop was unlike any other succession in the S.W. Province and a link with Belguim and Ireland was postulated with the reef development in the _Caninia_ Zone.

3. Aims of Research

During recent years there has been a growing concern about the utility of Vaughan's coral-brachiopod zones in the subdivision of the Carboniferous Limestone, as for instance by Kellaway and Welch (1955), who have replaced them by lithological names of local derivation.

Part of the purpose of this present work is to re-examine the basis upon which the zonal scheme rests, and to test its application in an area in which the rocks were known to be well exposed and where the general sequence was already established.

The particular importance of the _Caninia_ Zone in a zonal study is three fold:-

(a) Much of the criticism regarding the zonal scheme has been directed against the

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recognition and delineation of the *Caninia* Zone.

(b) The Tournaisian-Viséan junction occurred within this zone and there had been much conflict in the identification of this boundary.

(c) The rocks of the zone would show the effects of the mid-Dinantian ("Nassauian") movements, whose importance had been demonstrated in areas further east (George 1954, 1956).

The study has necessarily been along a number of lines (some of them pursued only tentatively) including:-

(i) The establishment of the limits and subdivision of the *Caninia* Zone on a sound palaeontological basis by systematic collection of fauna.

(ii) The search for lithological and faunal criteria to identify the Tournaisian-Viséan boundary.

(iii) The applicability of Cummings's foraminiferal zones to the sequence of coral-brachiopod assemblages.

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(iv) Petrographical analysis of the rocks in order to assess more accurately their depositional environment.

(v) The tracing laterally of individual rock units, noting lithological and faunal variations and thickness changes.

(vi) The assessment of the effects of the mid-Dinantian movements.

(vii) The correlation of the Pembrokeshire sequences with other areas in the S.W. Province.

(viii) The palaeogeographical synthesis of the accumulated evidence.

ACKNOWLEDGEMENTS

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II DINANTIAN ZONES IN PEMBROKESHIRE

The major criticisms directed against Vaughan's zones (Hudson and Dunnington 1944, George 1952, 1958, Rayner 1953, Kellaway and Welch 1955, Cummings 1958) are that they are defined less by palaeontological means than by lithological distinctions and doubts have been expressed whether they are applicable with any precision outside the Bristol district or even within the lithological units of the Avon section. In the present account, an acceptable subdivision is suggested of the Dinantian in Pembrokeshire and applied to the many subfacies within the limestone facies.

1. Definition of the Caninia Zone

The changing zonal nomenclature of the *Caninia* Zone has been reviewed by Hudson and Dunnington (1944 pp 210-213) and George (1958 pp 237-238).

The generally accepted limits of the *Caninia* Zone in the S.W. Province are those originally defined by Vaughan (1905 pp 260-261) in the Bristol

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district. It was equated to the *Syringothyris* Zone (C) and the Lower *Seminula* subzone (S_1) in the scheme adopted. Vaughan further subdivided it into the Lower *Caninia* Zone comprising the *Syringothyris* Zone with Horizon γ at the base, and the Upper *Caninia* Zone which was equated with the Lower *Seminula* subzone. The *Syringothyris* Zone was itself later subdivided (Dixon and Vaughan 1912 p. 482) into Lower (C_1) and Upper (C_2) subzones, and the latter was united with the Lower *Seminula* subzone (S_1), the modification being made on stratigraphical and palaeontological grounds. The horizon adopted for the division between C_1 and C_2 was the top of the *Caninia* Oolite or its equivalent horizon, where there is a sharp lithological change - emphasized in places by unconformity. This horizon was utilised by Dixey and Sibly (1918 p.118) as a more convenient subdivision of the *Caninia* Zone, and hence the widely accepted subdivision of the Zone, also used in the present account, into the Lower *Caninia* Zone comprising the Lower *Syringothyris*

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subzone (C_1), and the Upper *Caninia* Zone which is equated with the Upper *Syringothyris* (C_2) and the Lower *Seminula* (S_1) subzones.

The appearance of large caninioid corals in the succession marked the base of the Zone and their disappearance defined the top. Horizon γ, at the base, was originally defined by Vaughan (1905 p.193) as the horizon of overlap between the *Zaphrentis* and *Caninia* Zones and was said to be indicated by the coexistence of large caninioid and zaphrentoid corals. Later, Vaughan (1911 pp. 366 and 373) redefined the horizon as beds with *Caninophyllum patulum*[1] but without *Caninia cylindrica*. The incoming of *Davidsonina carbonaria* and the disappearance of the corals of the *Caninia cylindrica* group was taken to mark the top of the Zone and the base of the *Seminula* Zone.

[1] Authors of species of brachiopods and corals are quoted in the fossil list given on pp.148-160 otherwise, they are quoted at the first mention of a species.

2. Dinantian Stages.

In the S.W. Province the Lower Avonian is equated with the Tournaisian and the Upper Avonian with the Viséan and these are the terms used in the present account.

The division between the Dinantian Stages has been placed within the *Caninia* Zone. Unfortunately, there has been a great deal of conflict about where to place this boundary; it is proposed here briefly to review the evidence and to formulate an acceptable division.

It is not very important where this division is drawn provided that it is everywhere at the same horizon. In Britain, however, there have been several different suggestions as to where to place the Tournaisian-Viséan boundary (see George 1958, fig.3 p.238).

Vaughan, on palaeontological grounds, revised his earlier view in placing the junction at the base of S_1, and generally, except in the anomalous Burrington Combe Paper (1911), placed his junction not far above the base of C_2, where, he considered, the maximum faunal change occurred. In doing so, he defined an upper and lower C_2 fauna (1911 p.546); the lower fauna was considered to include forms which were in general characteristic of the Tournaisian, and the upper, forms characteristic of the Viséan. Essentially, the only difference was the presence of Lithostrotion in the upper C_2 fauna. However, Hudson and Dunnington took this faunal division of C_2 a step further by referring the Caninia Oolite of Burrington Combe and Glamorgan, with a fauna including Palaeosmilia murchisoni, early Koninckophyllum, Cravenia and Pericyclus kochi, to the lower part of C_2 zone. They further drew the division between the Tournaisian and Viséan at the base of the Caninia Oolite.

Dixon's interpretation has been accepted by most workers in the S.W. Province; the author follows his practice in placing the junction of the Tournaisian and Viséan at the top of the

Caninia Oolite or its equivalent horizon. In contrast to Vaughan's and Hudson and Dunnington's interpretations, it provides a clearly defined division of the Dinantian. As Vaughan pointed out, the faunal changes come above the _Caninia_ Oolite (and not at its base, as inferred by Hudson and Dunnington). Despite that the maximum expression of this faunal change is a little way above the junction, wth the establishment of _Lithostrotion_, the scheme adopted has widespread application.

3. The Tournaisian-Viséan Junction in Pembrokeshire.

The Tournaisian-Viséan junction defined above is everywhere recognizable in Pembrokeshire by a marked lithological and faunal change which reflects the mid-Dinantian movements. Over a large part of the area the _Caninia_ Oolite forms an easily recognizable and widespread formation. In the Tenby outcrop the succeeding basal Upper _Caninia_ Zone deposits are a "lagoon phase" in Dixon's sense (1921 p.72) and are overlain by light bioclastic limestones. To the south, in the Pembroke Syncline, the shallow-water development at the base is absent - the _Caninia_ Oolite is directly overlain by light, bioclastic limestones. Northwards from the "standard" development in the Tenby and Pembroke outcrop, the division between the two stages is defined by an unconformity between the Lower and Upper _Caninia_ Zones.

There is a broad continuity of sedimentation between the Tournaisian and Viséan in southernmost Pembrokeshire. In the Bosherston outcrop there is no _Caninia_ Oolite. Subdivision, however, is still possible since there is again an abrupt lithological change corresponding to the horizon of the _Caninia_ Oolite. A large part of the Tournaisian and the Lower Viséan is made up of "zaphrentid phase" deposits in Dixon's sense (1921 pp.72-73) and the term is also applied here to describe thin bedded, dark, bioclastic limestones with a rich fauna of solitary corals. However, the "zaphrentid phase" sedimentation is interrupted by the sudden incoming of massive reef in the succession. Dixon (1921 pp.126-129) drew his division between the stages at the top of the reef dolomite, considering the reef to be the "shallow water" /

equivalent of the _Caninia_ Oolite. In the view of the author, the division between the Tournaisian and Viséan is best taken at the marked lithological change at the base of the reef, which is considered to be a Sheet reef extending at least 10 miles across the depositional strike from Linney Head to Stackpole Quay.

The strong lithological grounds for a delimitation of the Dinantian Stages in Pembrokeshire are supported by major palaeontological contrasts. As already mentioned, the maximum expression of the faunal changes comes in a little way above the base of Upper _Caninia_ Zone. Thus, in the Pembroke and Tenby Synclines, _Lithostrotion_ enters about 150 feet above the top of the _Caninia_ Oolite. However, there is still an abrupt change directly above the Oolite and this is particularly well seen in the southern limb of the Pembroke Syncline where interbedded bioclastic calcarenites in the _Caninia_ Oolite yield in places a rich fauna. Elsewhere at this level in the oolitic facies, macrofossils are scarce, but /

the fauna, where present, has a Tournaisian aspect. Such forms as Schuchertella wexfordensis, Spirifer cf konincki (page 130) and Spirifer tornacensis (page 131) are found. The only additions to the fauna recorded in the Pembroke Syncline, when compared to the beds below, are early koninckophyllids.

In the beds immediately above the Caninia Oolite a comparatively rich and varied fauna appears in the succession. Such forms as Daviesiella destinezi and Caninia caninoides become established; Palaeosmilia murchisoni is abundant, and the faunal assemblage is further supplemented by the appearance of Lithostrotion in the middle of the Caninia Zone. Many forms, however, continue upwards from the Tournaisian; in particular, corals of the Caninia cylindrica group and Spirifer cf konincki survive.

Dixon placed his Tournaisian-Viséan junction in the Bosherston outcrop at the top of the reef dolomite. It was solely from its stratigraphical position that the reef was referred to C1, its fauna having been obliterated by dolomitization. Its age was inferred from the presence of a Viséan fauna in the beds immediately above the reef and a fauna supposedly characteristic of Horizon γ below. The 300 feet of "zaphrentid phase" limestones below the reef were assigned to Horizon γ by Dixon on the presence in the beds of Caninophyllum patulum without Caninia cylindrica (Dixon 1921 pp.65 and 125). In fact, Caninophyllum patulum enters 350 feet lower in the succession than the level at which it is recorded by Dixon, so that Horizon γ , in the sense defined above, would amount to at least 650 feet. The concept of Horizon γ , strictly defining a horizon of overlap between the Zaphrentis and Caninia Zones, is not applicable since the caninioid corals used by Vaughan to define it have a crude chronological significance. The presence of Caninophyllum patulum without Caninia cylindrica in the 650 feet of beds below the reef is not conclusive evidence that these beds should be assigned to the lower part of the Lower Caninia Zone. All that can be inferred from the fauna is that it is Tournaisian in age. Their stratigraphical position and the presence of high Tournaisian forms in these beds suggest that they may be referred to the upper part of the Tournaisian Main Limestone. These high Tournaisian forms include *Spirifer* cf. *konincki* (page 130), *Schuchertella* cf. *fascifera* (as interpreted by Demanet, page 141), *Schellwienella aspis* mut *radialiformis* (recorded from high Tournaisian Hook Head, Smyth 1930 p.585, as *S. aff. aspis*), the loosely septate form of *Caninophyllum patulum* (high in the Tournaisian at Hook Head, Smyth 1930 p.551, and Burrington Combe, Mitchell personal communication) early koninckophyllids and *Cravenia* (uppermost Tournaisian in Glamorgan).

The evidence suggests that the boundary between the two stages should be drawn below the reef dolomite and not at its upper limit. This is strongly supported by the incoming of *Lithostrotion* in the beds directly overlying the reef in the Bosherston outcrop. Everywhere in the S.W.Province *Lithostrotion* enters in the lower part of the Upper *Caninia* Zone and not at its base. Its appearance in the Bosherston outcrop, presumably at a comparable horizon in the Upper *Caninia* Zone, establishes the reef as basal Viséan in age.

In the beds above the reef abundant new forms appear, although many Tournaisian forms persist upwards (see page 94). Corals of the Caninia cylindrica group replaces Caninophyllum patulum as as the dominant caninioid form (Caninia cylindrica is found earlier elsewhere); moreover, Caninia caninoides, Zaphrentites konincki mut kentensis (Garwood) (mut. C_2 Vaughan 1911 pp.368-369, see also Hudson and Mitchell 1937 page 9 , footnote), and Daviesiella destinezi becomes established together with a host of new forms discussed in the palaeontological section (see page 95).

4. Subdivision of the Dinantian Stages in Pembrokeshire

Despite the many limitations of Vaughan's zones they have been generally accepted and found applicable in the S.W.Province (George 1958 pp. 233-234). Nevertheless, their precise definition is not without difficulty, not merely because of the changing criteria used to define them but also because of the complications of correlation in rocks of varying facies. However, from a study of the Dinantian fauna in

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Pembrokeshire it has become apparent that many of the forms are tolerant of a relatively wide variety of environmental conditions and occur abundantly in different facies. Thus, the author has been able to recognize the following subdivision of the Dinantian stages in each outcrop in the area.

(a) Subdivision of the Tournaisian Stage

The study of the ranges of the characteristic Tournaisian brachiopods and corals in Pembrokeshire has helped to elucidate the reliability of these forms for the subdivision of the stage. The ranges of the characteristic forms which, Vaughan, Dixon and others used to define the Tournaisian zones have been seen to show only crude chronological significance. The conventional subdivision of the stage into K, Z, C_1, is not practicable. There is no reliable or precise distinction between the zones except perhaps locally. In the appropriate rock facies the forms may enter at a lower horizon and persist to a higher horizon than in the more typical developments. This is particularly well seen in the Bosherston

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outcrop, where there is a dominant bioclastic facies which is broadly persistent through several thousands of feet of beds above the Lower Limestone Shales. When the ranges of the faunas of the "standard" development in Pembrokeshire and the Bristol district are compared with the ranges of these same forms in the Bosherston outcrop, it will be seen that the application of the limited criteria laid down by Vaughan is impossible. It is evident that Dixon himself, though he wrote at a time when the applicability of Vaughan's scheme was a source of exciting discovery also found this difficulty. There was in south Pembrokeshire a free migration of a rich fauna unparalleled elsewhere in the S.W.Province.

The author following George (1958 p.237) employs a lithological-faunal division rather than a strictly palaeontological one. Thus, the Tournaisian is divided into the "Cleistoporan" Lower Limestone Shales (though it is doubtful if they are any more than a lithological group) with extremely rare Rugose corals, and the Tournaisian Main Limestone with zaphrentoid

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and caninioid corals.

Essentially the above groupings are no more than a modification of Vaughan's divisions, the Lower Limestone Shales being equated with the *Cleistopora* Zone, and the Tournaisian Main Limestone with the *Zaphrentis* and Lower *Caninia* Zones. Moreover, the author has found it convenient to continue using Vaughan's groupings locally in Pembrokeshire, though it is doubtful whether these faunal divisions are placed everywhere at the same horizon. For example, the incoming of the zaphrentoid corals, used to define the base of *Zaphrentis* Zone occurs at the base of the Lower Limestone Shales at Stackpole Quay and in the Angle Syncline in south Pembrokeshire. Similarly, the appearance of caninioid corals defining the lower limits of the *Caninia* Zone is equally unreliable. It has resulted notably in Horizon γ having been misunderstood. In Pembrokeshire, for example, Horizon γ was applied in two different ways by Dixon (1921 p.63). In the Pembroke Syncline, it was used in the sense originally defined by Vaughan(1905), that is, to comprise the beds in which zaphrentoids and large caninioid corals coexisted. If this definition of Horizon γ was applied to the Bosherston outcrop then the Horizon would extend from the base of the Tournaisian Main Limestone to the top of the Upper Caninia Zone. As a result, Dixon in southernmost Pembrokeshire used it in the sense defined by Vaughan in Burrington Combe (1911 pp.366 & 373) to comprise beds with Caninophyllum patulum but without Caninia cylindrica.

Horizon γ , as defined by Dixon, is 650 feet thick in the Bosherston outcrop, 200 feet in the southern limb of the Pembroke Syncline and approximately 100 feet in the northern limb. In the Pembroke Syncline the Horizon was represented by a coarse crinoidal limestone, "petit granit" of Belgium stratigraphers. Caninia cylindrica enters 100 feet above the base of Horizon γ in the southern limb of the Syncline (as a result, applying Vaughan's 1911 definition, Horizon γ would only be 100 feet rather than 200 feet). The confusion becomes even greater north of the Pembroke Syncline where Horizon γ

cannot be recognized because the incoming of caninioid corals was not recorded. This is probably because the caninioids were destroyed by dolomitization affecting the middle of the Tournaisian Main Limestone, though they may well have been originally absent as a reflection of a facies change.

Further evidence for the unreliability of Tournaisian corals may be seen from their distribution in Belgium, where caninioid and zaphrentoid corals are recorded from the Strunian beds, while the order of incoming of *Caninia cylindrica* and *Caninophyllum patulum* is reversed with respect to the British succession. It seems likely that the appearance of the caninioid corals in Britain reflects a relatively later immigration.

(b) Subdivision of the Viséan Stage

It has already been emphasized that in the Dinantian changes in fossil assemblages can be related to changes in sedimentation, which, in their turn, reflect the influence of earthmovements.

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Such movements were generally absent in the Tournaisian so that no widespread sharp lithological and faunal contrasts exist on which to subdivide it. On the other hand, earthmovements were widely felt in the Viséan. Movements between the Lower and Upper *Caninia* Zones served to delimit Tournaisian from Visean, movements between the Upper *Caninia* and *Seminula* Zones (first demonstrated by George 1954, 1956) facilitated the definition of the top of the *Caninia* Zone. Moreover, current work seems to substantiate the suggestions of Dixon and Vaughan (1912 p.536) and George (1927 p.74) that the widespread faunal and lithological changes between the *Seminula* and *Dibunophyllum* Zones may likewise be related to earthmovements.

It has been found convenient in Pembrokeshire to subdivide the Viséan into three well defined stratal groupings approximating to the Upper *Caninia* Zone, *Seminula* Zone and *Dibunophyllum* Zone of Vaughan's faunal scheme.

It has already been shown that the Upper *Caninia*

Zone can no longer be defined by solely the presence of corals of the _Caninia cylindrica_ group, since they continue into the overlying _Seminula_ Zone over a large part of Pembrokeshire. Instead, the author has identified the Zone in the various outcrops in the area by such diagnostic forms as _Daviesiella destinezi_, _Caninia caninoides_ and the abundance at this level of _Palaeosmilia murchisoni_. Only the latter appears not to be confined to this Zone. Moreover, _Lithostrotion_ becomes established in the middle of the Zone and smooth athyrids (_Composita_) and linoproductids become abundant.

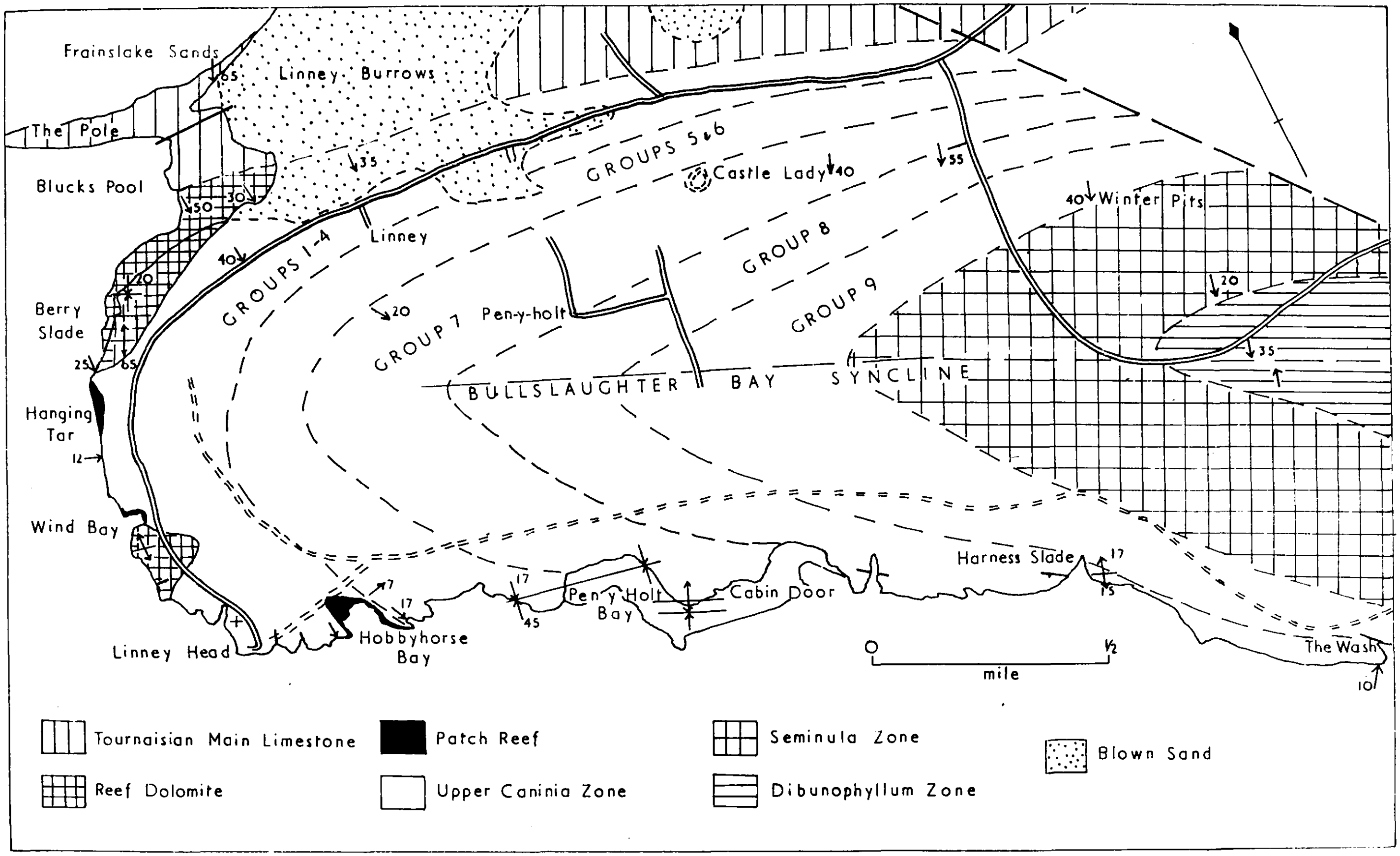
The _Seminula_ and _Dibunophyllum_ Zones are readily recognized by the incoming of diagnostic forms and by abrupt changes in lithology. The only reliable index fossil of the former is _Davidsonina carbonaria_ which has a widespread distribution in Pembrokeshire.

III SUCCESSION AND LATERAL VARIATION IN THE TOURNAISIAN MAIN LIMESTONE

The Dinantian succession in Pembrokeshire has been outlined by Dixon (1914 & 1921) and it is proposed in the present account to particularize where he has generalized. Greater discrimination is shown in the study of the detailed lithology and lateral variation in the mid-Dinantian succession in order to assess more accurately the depositional environment. The upper part of the Tournaisian Main Limestone and the Upper *Caninia* Zone are alone considered in detail, that is, that part of the succession which composes Dixon's *Caninia* Zone.

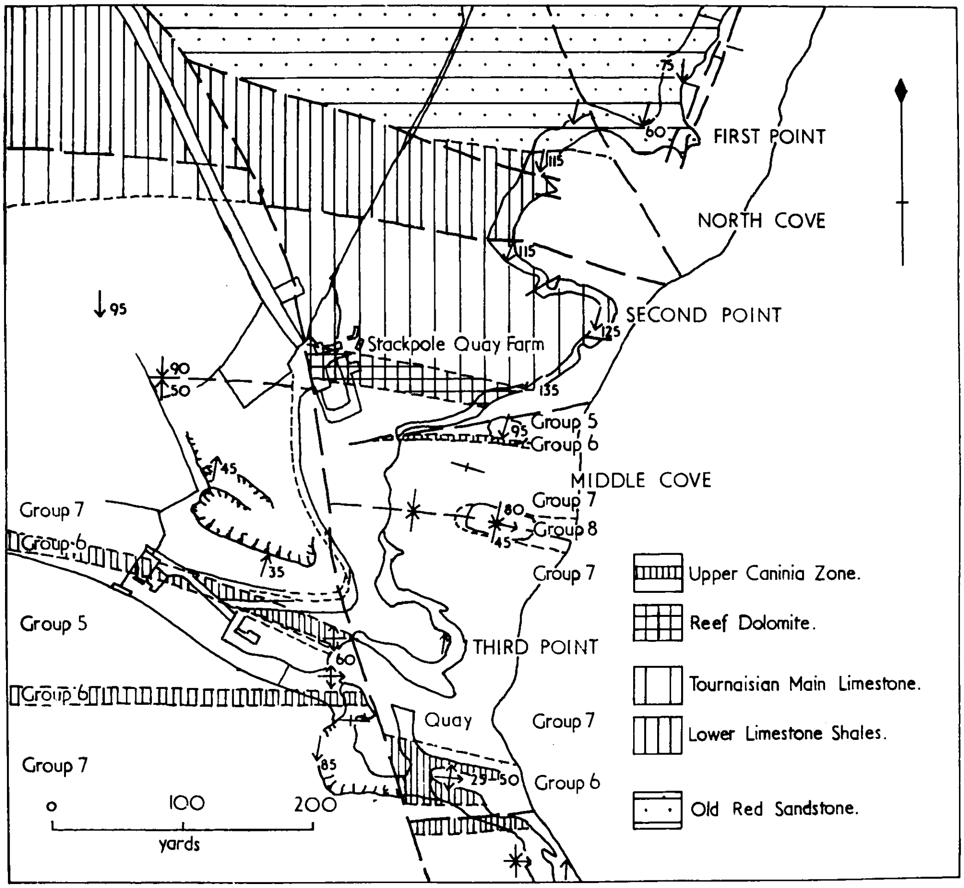
Over much of Pembrokeshire there is a comparatively rapid change from Lower Limestone Shales into the Main Limestone. The Main Limestone is foreshadowed by the appearance of thin limestones in the upper part of the Lower Limestone Shales but, nevertheless, a horizon of maximum lithological change is recognizable when limestones become dominant in the succession, though shales recur at intervals in the lower part of the Main Limestone. It is at about this level that chert in profusion appears. Accompanying the change, and no doubt correlated in part

Fig. 3 Map of the geology of the Bucks Pool - Linney Head area (amended after Dixon, 1921 fig. 10 p. 124). The groups of the Upper *Caninia* Zone refer to Dixon's groups (1921 pp 120-131) and their boundaries inland are largely hypothetical.



Frainslake Sands
Linney Burrows
The Pole
Blucks Pool
Berry Slade
Hanging Tar
Wind Bay
Linney Head
Hobbyhorse Bay
Pen-y-Holt Bay
Cabin Door
Harness Slade
The Wash
Linney
Pen-y-holt
Castle Lady
Winter Pits
GROUPS 1-4
GROUPS 5 & 6
GROUP 7
GROUP 8
GROUP 9
BULLSLAUGHTER BAY SYNCLINE
0
½
mile
Tournaisian Main Limestone
Reef Dolomite
Patch Reef
Upper Caninia Zone
Seminula Zone
Dibunophyllum Zone
Blown Sand

Fig. 4 Map of the geology of Stackpole Quay (amended after Dixon, 1921 fig. 5 p. 60). The groups of the Upper _Caninia_ Zone refer to Dixon's Groups (1921 pp 130-131).



FIRST POINT
NORTH COVE
SECOND POINT
Stackpole Quay Farm
Group 5
Group 6
MIDDLE COVE
Group 7
Group 8
Group 7
Group 6
Group 7
Group 5
THIRD POINT
Group 6
Quay
Group 7
Group 7
Group 6
0
100
200
yards
Upper Caninia Zone.
Reef Dolomite.
Tournaisian Main Limestone.
Lower Limestone Shales.
Old Red Sandstone.

at least with it, is a marked increase in the abundance of zaphrentoid corals.

1. Bosherston Outcrop

The Tournaisian Main Limestone is well displayed in the northern limb of the Bullslaughter Bay Syncline along the shore between Frainslake and Blucks Pool (see fig.3). Dixon (1921 pp.123-126 and p.139) described a little over 1000 feet of Tournaisian Main Limestone which he referred to the *Zaphrentis* Zone and Horizon γ . The base of the succession is concealed and its relationship with the Lower Limestone Shales, which are exposed in the extreme north of Frainslake, is unknown. When that part of the succession not seen is allowed for, the total thickness of Tournaisian Main Limestone is probably of the order of 1,500 feet.

The beds in Blucks Pool dip steeply (60°) to the south and the succession is apparently continuous, except for a small strike fault at the northern margin of Blucks Pool, to the base of the dolomitized reef limestones. There is no evidence to substantiate the presence of a cross fault (Dixon 1921 fig.10 p.124) terminating the succession in Blucks Pool.

The Tournaisian Main Limestone reappears in the eastern part of the Bosherston outcrop at Stackpole Quay (see fig.4). As Dixon showed (1921,pp.129-130 and p.139) the succession is observed in a highly faulted and inverted sequence in which the Tournaisian Main Limestone structurally underlies the Lower Limestone Shales and structurally overlies the dolomitized reef limestone (the <u>Laminosa</u> Dolomite of Dixon).

Lithologically the succession resembles the Blucks Pool sequence; but at Stackpole Quay only 220 feet of rocks are referable to the Tournaisian Main Limestone. As pointed out by Dixon (1921 p.129), the succession probably consists of the lowest beds and the upper part of the Tournaisian Main Limestone exposed at Blucks Pool. The lowermost 70 feet, faulted against Lower Limestone Shales to the north of Second Point (see fig.4) consist of dark bioclastic limestones and thin shales with small transverse <u>Spirifer tornacensis</u>, small chonetids and zaphrentoid corals: they are comparable with Group 1 of the Blucks Pool sequence (Dixon 1921 p.125). The uppermost beds, described by Dixon (1921 p.129) in the

Stackpole Quay sequence is referred to the upper part of the Tournaisian Main Limestone since they underlie the reef dolomite without any obvious structural break and contain a high Tournaisian fauna including Caninophyllum patulum. The two groups of the Tournaisian Main Limestone are separated by a thrust exposed north of Second Point and it is possible that other small thrusts exist which have not been recognized whose effect is similarly to eliminate much of the succession.

The Tournaisian Main Limestone in the Bosherston outcrop is described by Dixon as a succession of "zaphrentid phase" limestones. He applied the term to dark thinly bedded limestones with interbedded shales and mudstones which are particularly rich in solitary corals. The term is retained to describe such an association. Individual posts of limestones rarely exceed two feet, the top and bottom of the limestones are sharply delimited from the overlying and underlying mudstones. In hand specimens, the limestones are fine and evenly grained with occasional nests and veins of coarsely crystalline calcite. In the neighbourhood of faults particularly, the limestones are often decalcified, weathering to a brown iron-rich residue, limonite being often concentrated in nodules. Dolomite is sporadically developed and gives a buff-weathering patchy surface to many of the rocks. Chert is abundant and replaces the limestones. It is usually dark in colour, nodular, and of secondary origin.

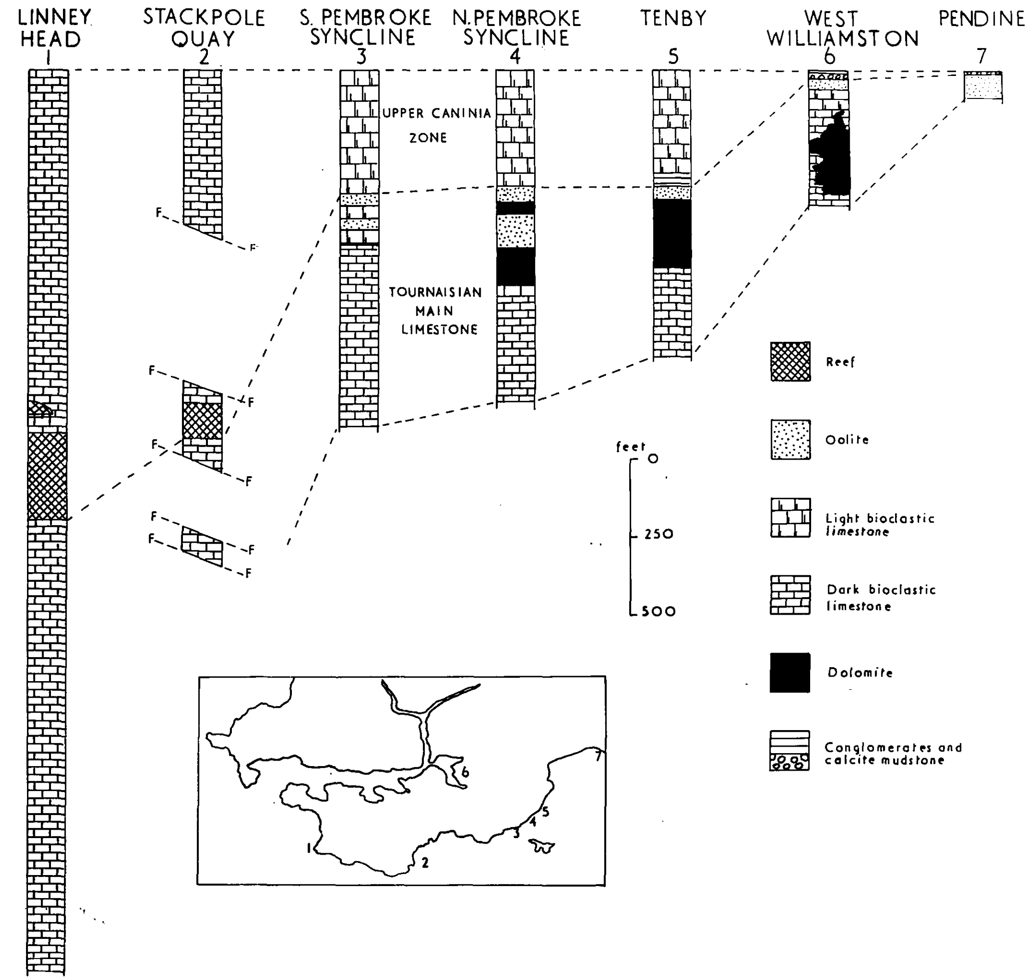
The calcareous mudstones interbedded in the sequence are less resistant than the limestones to weathering. They are generally unlaminated, dark, often dolomitized and iron-stained showing in places prominent fracture cleavage. Associated with and interbedded in the mudstones are nodular limestones which are probably of secondary origin (see page 62).

Microscopically, the limestones are fine-grained bioclastic calcarenites and are almost entirely made up of crinoids, brachiopods and molluscs and abundant bryozoa, algae and foraminifera set in a dark fine matrix (see plate IX). The matrix is highly argillaceous which gives the dark colour to the rock. Bryozoa are particularly abundant in the "zaphrentid phase" deposits. Cryptostomatous forms are the commonest, the fenestrules often being infilled by fine granules of calcite. The limestones exhibit varying degrees of recrystallization, alteration being more extensive in the lower part of the Tournaisian Main Limestone where the greater part of the rock is often replaced by fine granular calcite. The replacement appears to be selective, affecting the groundmass while leaving the large detrital grains unaltered. When the limestones are dolomitized, small euhedral rhombs of dolomite are distributed through the rock. Occasional rhombs of magnetite are locally abundant in the limestones.

In thin section the mudstones are seen to be composed almost entirely of fine opaque argillaceous mud, rich in bryozoa, but there is a conspicuous absence of the abundant organic remains found in the associated limestones.

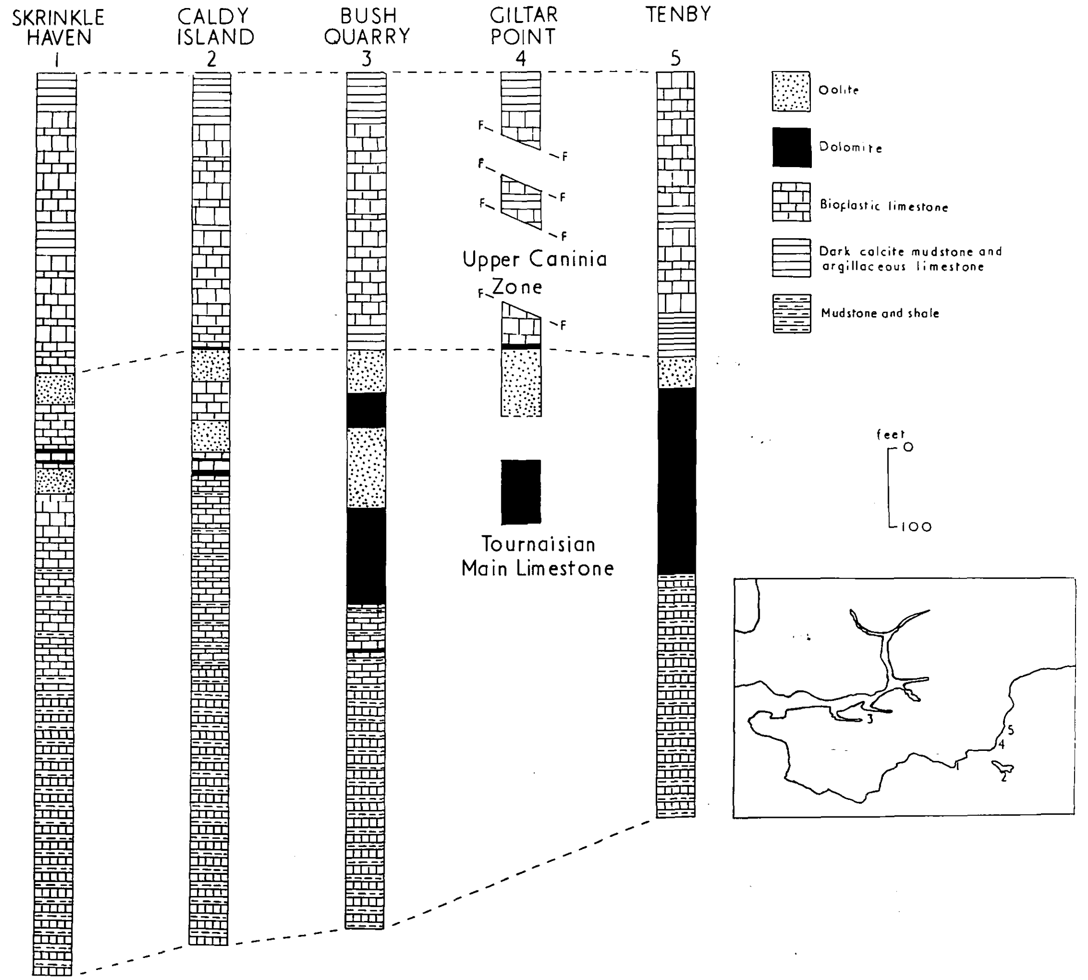
The fauna in the "zaphrentid phase" limestones consists mainly of a rich and varied coral-brachiopod-bryozoan assemblage. Many of the fossils are silicified and often admirably displayed by differential weathering. The distribution of the fauna is described later.

Fig. 5 Comparative section of the Tournaisian Main Limestone and Upper *Caninia* Zone of Pembrokeshire showing the northward thinning and development of mid-Dinantian unconformities.



LINNEY HEAD
1
STACKPOLE QUAY
2
S. PEMBROKE SYNCLINE
3
N. PEMBROKE SYNCLINE
4
TENBY
5
WEST WILLIAMSTON
6
PENDINE
7
UPPER CANINIA ZONE
TOURNAISIAN MAIN LIMESTONE
F
feet
0
250
500
Reef
Oolite
Light bioclastic limestone
Dark bioclastic limestone
Dolomite
Conglomerates and calcite mudstone

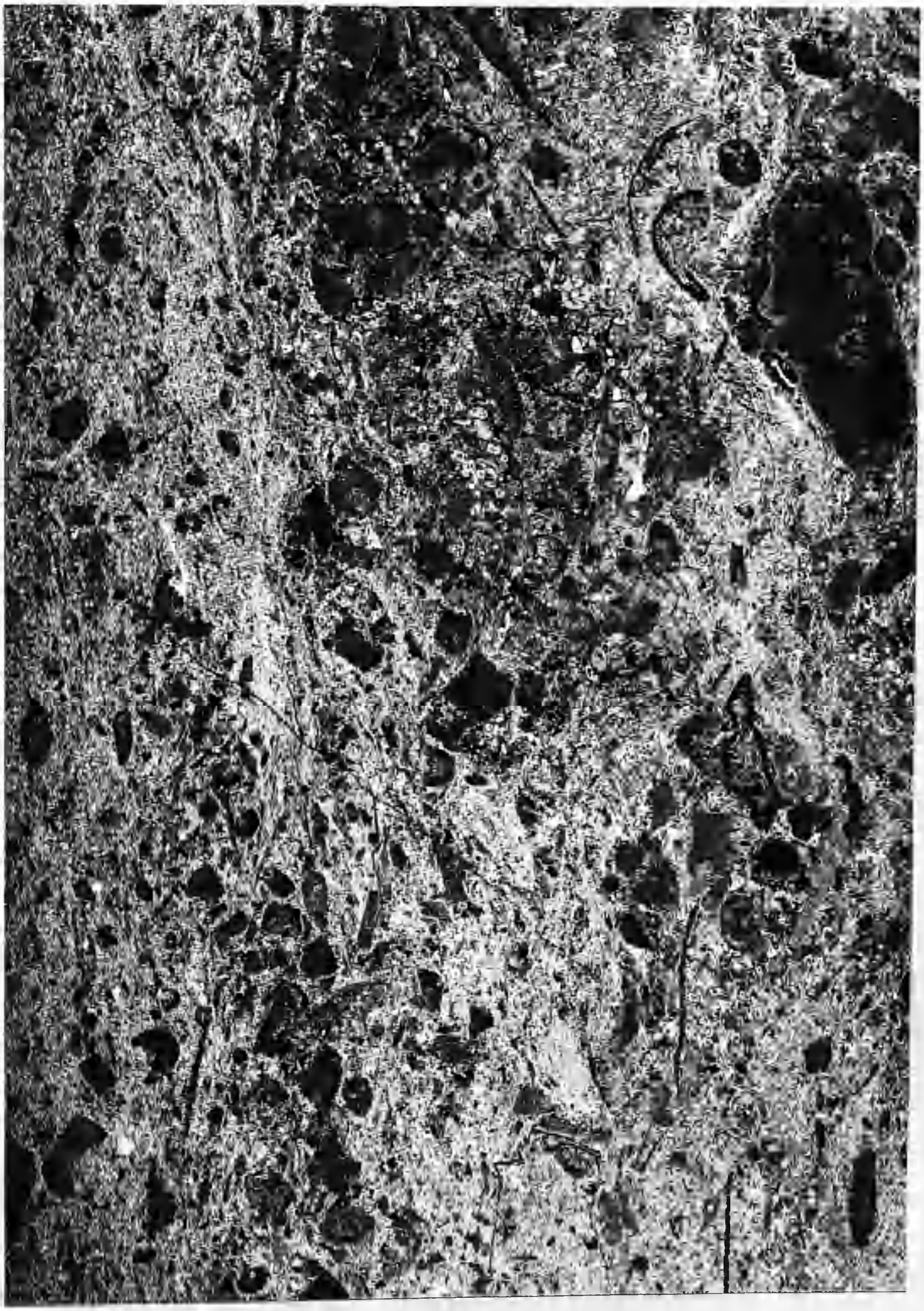
Fig. 6 Comparative section showing the lateral variation displayed by the Tournaisian Main Limestone and the Upper *Caninia* Zone across the Pembroke and Tenby Synclines.


SKRINKLE HAVEN
1
CALDY ISLAND
2
BUSH QUARRY
3
GILTAR POINT
4
TENBY
5
Oolite
Dolomite
Bioclastic limestone
Dark calcite mudstone and argillaceous limestone
Mudstone and shale
Upper Caninia Zone
Tournaisian Main Limestone
feet
0
100

EXPLANATION OF PLATE I

Bioclastic limestone. Poorly sorted bioclastic limestone composed dominantly of crinoid and shell fragments; the rock is rich in bryozoa, echinoid spines and foraminifera (including plectogyrids and earlandiids). This is the typical lithology of a large part of the Tournaisian Main Limestone in the Pembroke Syncline.

Upper part of Tournaisian Main Limestone (200 feet below the top of Tournaisian) near Skrinkle Haven. (x 7½) The photograph is a negative.



2. Pembroke and Tenby Synclines

Northwards from the Bosherston outcrop the Tournaisian Main Limestone thins (see figs.5 and 10). The bioclastic facies of southernmost Pembrokeshire persists through a large part of the Tournaisian Main Limestone. However, in the upper part of the succession oolites appear reflecting the onset of mid-Dinantian movements.

The sequences in the Pembroke and Tenby Synclines have been described by Dixon (1921 pp.88-89, 93-95, 99-101, 106-111).

The bioclastic limestones in the lower part of the Tournaisian Main Limestone are "zaphrentid phase" sediments similar in lithology to those in the Bosherston outcrop. The limestones are fine grained calcarenites near the base but the amount of crinoid debris and shell fragments increases in proportion upwards in the succession and near the top of the group the limestones are coarse calcarenites. Interbedded in the limestones are thin calcareous shales which clearly exhibit the thin transitional development of weakly fissile argillaceous limestones passing upwards and downwards into laminated shales. They contrast with the "zaphrentid phase" limestones of the Bosherston outcrop where mudstones predominate over shales in the succession and the junction between the mudstone and limestone is abrupt. Dark nodular cherts are mainly confined to the lower part of the bioclastic limestones.

The high proportion of muddy detritus in these beds is reflected in the microlithology of the limestones. The limestones are made up of abundant organic fragments including abundant crinoid and brachiopod remains, bryozoans, calcispheres, ostracods, and foraminifera embedded in a dark fine matrix which is markedly argillaceous (see plate..1...).

In the upper part of the Tournaisian Main Limestone oolites are represented in the succession. In the southern limb of the Pembroke Syncline light bioclastic limestones are interbedded with the oolites but northwards the oolites thicken and the bioclastic limestones are only represented by occasional thin layers in the oolites in the northern limb of the fold and in the Tenby outcrop.

By comparison with the "zaphrentid phase" limestones in the lower part of the Tournaisian Main Limestone, the upper bioclastic limestones are well-sorted, lighter in colour and more massive. The dark interbedded shales and mudstones are absent, as is the secondary chert. The bioclastic limestones are readily distinguished from the associated oolites in the field by their darker weathering and often selective dolomitization.

Under the microscope they are seen to be coarse calcarenites and show a more mixed bioclastic character than is evident in the hand specimen. They are well-sorted and consist of abundant abraded crinoid and brachiopod fragments with common bryozoa, foraminifera and algae set in a clear matrix of coarse recrystallized calcite.

The associated oolites (the *Caninia* Oolite of Dixon) are white weathering, massive limestones whose shallow-water origin is inferred from the current bedding. They form two thick units separated by bioclastic limestones in the southern limb of the Pembroke Syncline (see fig. 6) but northwards they coalesce. In parts, the oolites are highly crinoidal and strings of shell and crinoid debris are scattered throughout.

In thin section the ooliths are broadly uniform in size though many are irregular in shape; their forms appearing to be controlled by their detrital nuclei of which many are crinoid remains, shell fragments and foraminifera. The ooliths are set in a clear coarse recrystallized matrix of calcite (see plate 11). The ooliths are darker than the groundmass possibly due to a dark film of algal "dust" (Wood 1941 p.127 and George 1954 p.293) and show concentric layering. Foraminifera and algae are fairly common in the oolites.

When the Tournaisian Main Limestone is traced northwards in the Pembroke and Tenby Synclines secondary dolomitization increases in the upper part of the succession and obliterates the primary sediments. In the southern limb of the Pembroke Syncline dolomites are only sporadically developed and occur as thin bands in the succession. However, in the northern limb of the fold dolomitization amounts to about 125 feet of dark dolomites (the Laminosa Dolomite of Dixon) in the upper part of the Tournaisian Main Limestone (see fig. 6). It is seen replacing the lower part of the oolite in the

EXPLANATION OF PLATE II

Oolitic bioclastic limestone. Brachiopods, crinoid fragments and foraminifera are prominent among the organic constituents. The foraminifera included earlandiids, plectogyrids and tournayellinids. The ooliths and organic fragments are set in a clear sparry calcite matrix.

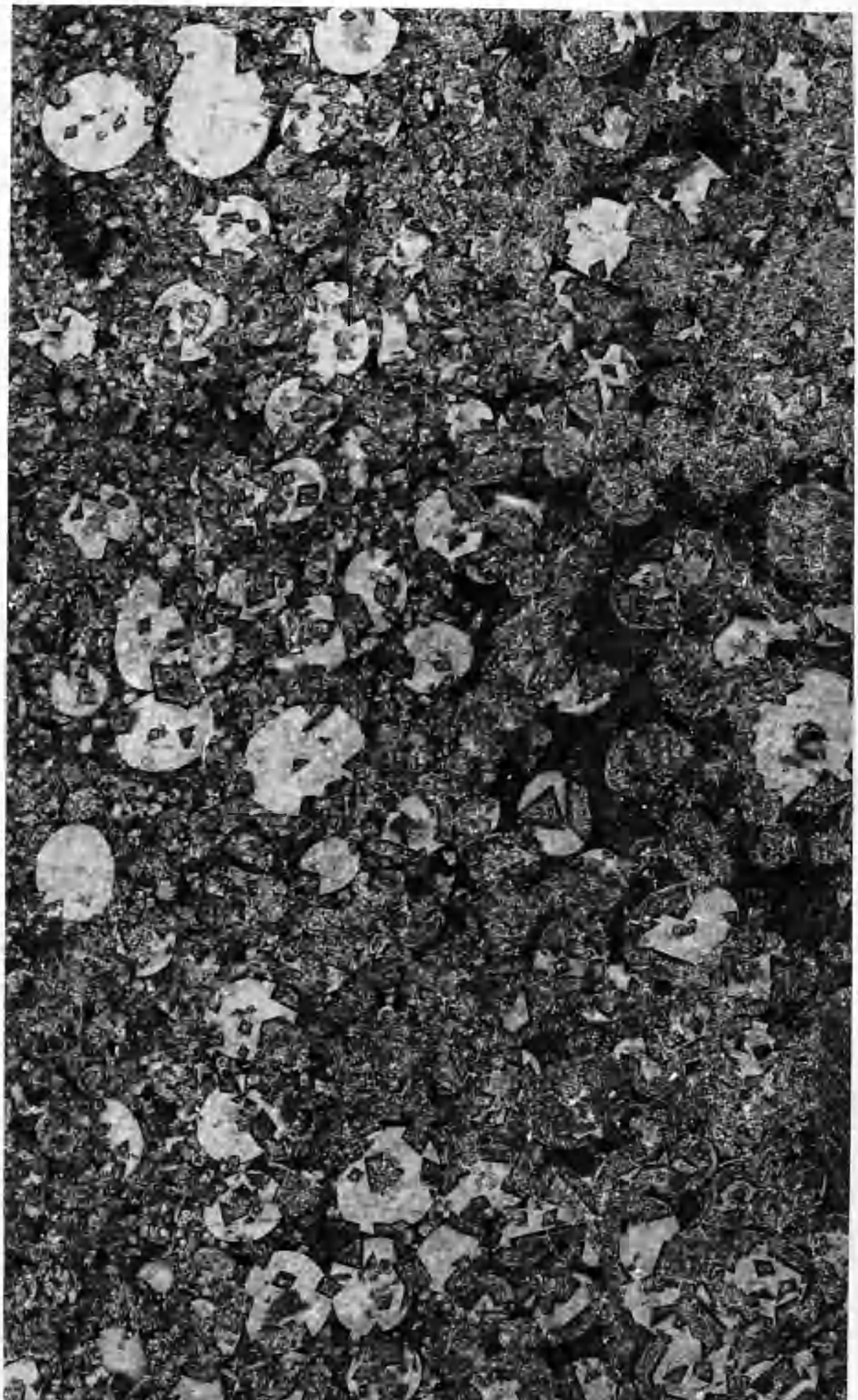
Top Caninia Oolite, Black Mixen, Pembroke Syncline.

(x18) The photograph is a negative.

EXPLANATION OF PLATE III

Dolomitized oolitic limestone, oolitic limestone being replaced by secondary dolomite.

Upper part *Caninia* Oolite, Giltar Point, Pembroke Syncline. (x 18) The photograph is a negative.



sequence but it is probable that the larger part of it is a metasomatic replacement of bioclastic limestones. In the Tenby outcrop dolomitization is very extensive, affecting the greater part of the higher Tournaisian Main Limestone beds.

Typically the dolomites are dark fine-grained buff weathering rocks made up of finely crystalline dolomite and containing abundant small nests of white dolomite and calcite. They are of undoubted secondary origin, not "contemporaneous" as postulated by Dixon (1921 p.70) but "subsequent" in the sense used by George (1954 p.290, footnote). In thin section the dolomites are seen to consist of small interlocking grains of dolomite completely replacing the original calcitic constituent.

3. <u>The West Williamston Outcrop</u>

Dixon (in Strahan and others 1914 pp.137-139) described the succession in the West Williamston outcrop, referring the 400-500 feet of Tournaisian Main Limestone collectively to "ZC_1", dolomitization having obliterated most of the fauna and making further subdivision difficult. The Tournaisian Main Limestone is, however, again divisible into a thick lower bioclastic group and a thin upper oolite group.

The succession is best exposed near Carew Castle and on the fore-shore of Carew River (see fig. 7) where the following sequence occurs:-

		Approximate thickness in feet
5.	Light massive oolitic limestones, the _Caninia_ Oolite of Dixon	40
4.	Massively bedded light bioclastic limestones	50
3.	Thin bedded dark bioclastic limestones with thin inter-bedded calcareous shales	60
2.	Dark finely crystalline dolomites exposed between Carew Mill and Ford Point along the Carew River	200
1.	Dark thin bedded bioclastic limestones with thin shales. The base is hidden beneath the estuary but presumably rests on Lower Limestone Shales	50

The dark bioclastic limestones (beds 1 and 3) are closely comparable with the "zaphrentid phase" deposits to the south. They are dominantly calcarenites, poorly sorted and rich in crinoid and brachiopod fragments. They are highly argillaceous and contain interbedded shales. Cherts are irregularly distributed in the lower part.

Fig. 7 Map of the geology of the West Williamston area.

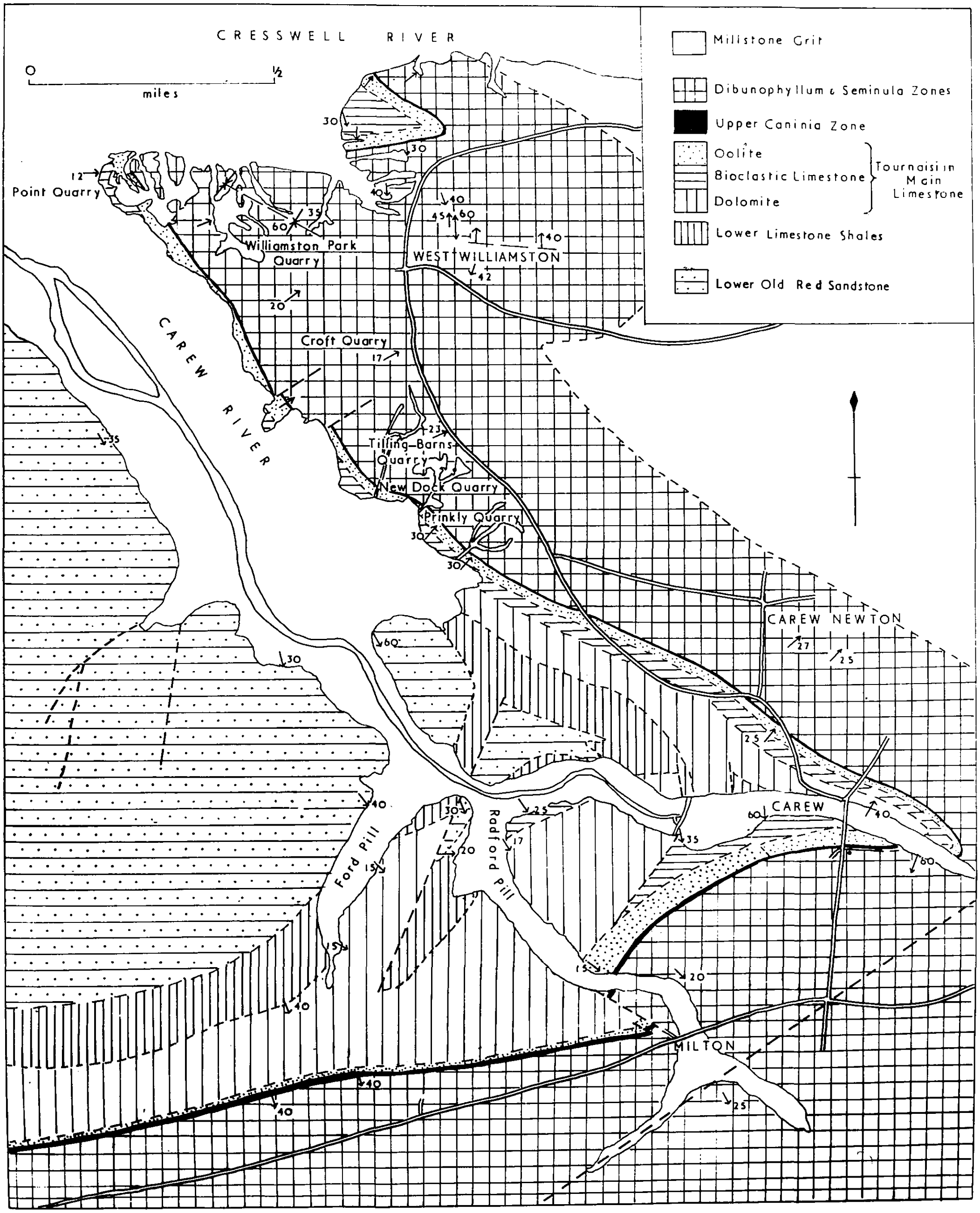
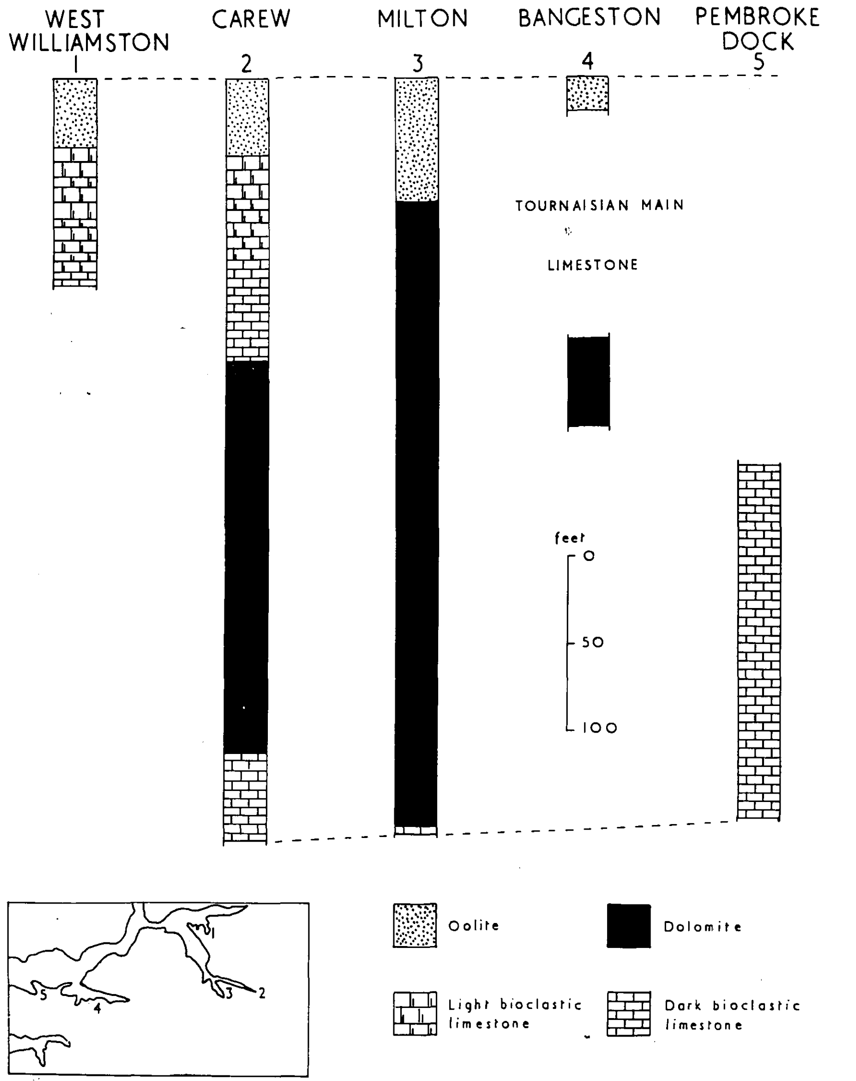

CRESSWELL RIVER
0
½
miles
Millstone Grit
Dibunophyllum & Seminula Zones
Upper Caninia Zone
Oolite
Bioclastic Limestone
Dolomite
Tournaisian Main Limestone
Lower Limestone Shales
Lower Old Red Sandstone
Point Quarry
Williamston Park Quarry
WEST WILLIAMSTON
CAREW RIVER
Croft Quarry
Tilling-Barns Quarry
New Dock Quarry
Prinkly Quarry
CAREW NEWTON
CAREW
Ford Pill
Radford Pill
MILTON

Fig. 8 Comparative section of the Tournaisian Main Limestone between West Williamston and Pembroke Dock.


WEST WILLIAMSTON
1
CAREW
2
MILTON
3
BANGESTON
4
PEMBROKE DOCK
5
TOURNAISIAN MAIN
LIMESTONE
feet
0
50
100
1
2
3
4
5
Oolite
Dolomite
Light bioclastic limestone
Dark bioclastic limestone

These mixed sediments grade upwards in the upper part of the Tournaisian Main Limestone to lighter well-sorted calcarenites (bed 4), similar to the calcarenites interbedded in the oolites in the Pembroke Syncline. They are once more coarse grained composed of abraded crinoid and other shell fragments, plentiful foraminifera set in a clear matrix of strongly recrystallized calcite. In the upper part occasional ooliths are scattered through the rock which passes quickly in upward sequence first into shelly oolites and finally into true oolitic limestones. The transition is rapid and takes place through ten feet or so of rock. The *Caninia* Oolite at West Williamston is identical in lithology to the oolite in the upper Tournaisian to the south.

Dolomites make up a considerable part of the succession and the original nature of much of the limestones is no longer evident though the occasional occurrence of less completely dolomitized beds suggest that most of the primary rocks were bioclastic sediments.

Lateral variation in the Tournaisian Main Limestone

Only the upper part (beds 3 and 4) of the Tournaisian

Main Limestone recognized at Carew can be traced northwards along the shore of the Carew River to West Williamston (see fig. 8). There is little variation when the beds are traced laterally - the *Caninia* Oolite remaining fairly constant in thickness and lithology. 40 feet of oolites are exposed in the Point Quarry and are underlain by 80 feet of light bioclastic limestones, the base is hidden beneath the mud of the estuary. At West Williamston the top of the *Caninia* Oolite is eroded and pocketed and offers the first lithological evidence for the mid-Dinantian break.

Westwards from Carew along the Pembroke Dock part of the outcrop, dolomitization in the succession increases and the groups defined at Carew are not traceable. At Milton 65 feet of *Caninia* Oolite with thin bioclastic layers in the lower part is underlain directly by dolomites which continues to near the base of the Tournaisian Main Limestone. The rocks are badly exposed further west but the succession continues to be greatly affected by dolomitization, and along Cosherston Pill (see fig. 8) only the uppermost 20 feet of the *Caninia* Oolite can be recognized, the remainder of the

Tournaisian Main Limestone appearing to be completely dolomitized.

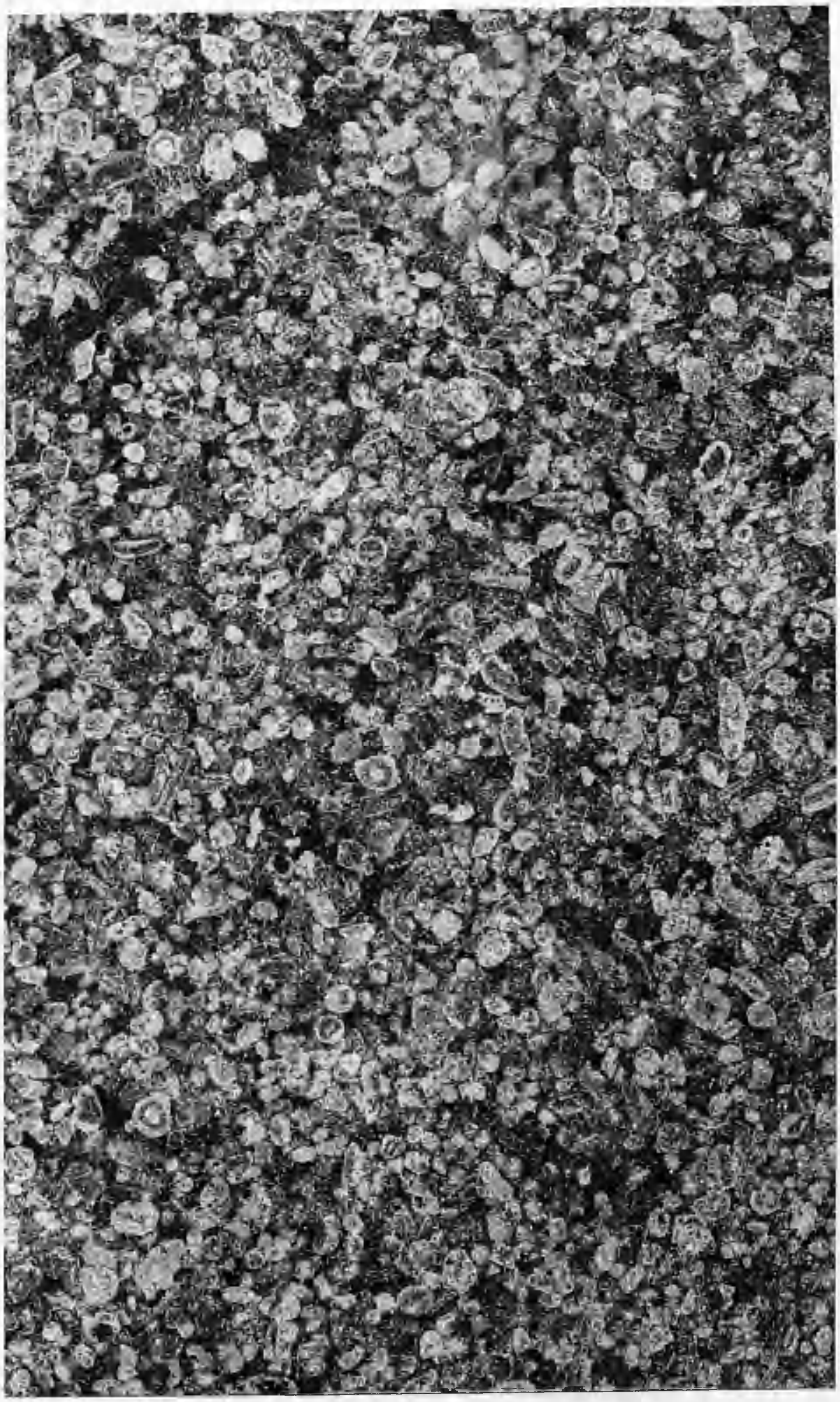
In the extreme west of the outcrop, south of Carr's Rock Pembroke Dock, dolomitization diminishes near the base of the succession and 200 feet of the lower part of the Tournaisian Main Limestone is undolomitized. It is seen to consist of dark thin bedded bioclastic limestones with thin shales, identical in lithology with beds 1 and 3 at Carew, and overlies the Lower Limestone Shales.

EXPLANATION OF PLATE IV

Oolitic bioclastic limestone. The rock is composed dominantly of ooliths, often uniform in size, with abundant organic fragments. Many of the organic fragments have a thin coating of fine-grained calcite-mud. The matrix consists of strongly recrystallized, sparry calcite.

Oolite Group, Pendine. (x 18)

The photograph is a negative.



4. North Crop of Pembrokeshire

Dixon (in Strahan and others 1914 pp.130-135) summarized the sedimentary relationship on the North Crop between Pendine and Haverfordwest. Emergence of St. George's Land to the north in mid-Dinantian times resulted in the Tournaisian Main Limestone being eroded along the North Crop and the group is absent along the western part of the outcrop.

(a) Succession at Pendine and Cloygen Quarry

In the extreme east of the outcrop 70 feet of Tournaisian Main Limestone are present below the Visean. The rocks are mainly, massively bedded, light highly recrystallized oolitic limestones (the Oolite Group) amounting to 60 feet at Pendine, underlain by 12 feet of thin-bedded dark crinoidal limestones with sporadically developed dolomites. The base of the succession is hidden beneath the sand at Pendine but Lower Limestone Shales crops out close-by.

There is an abrupt junction at the base of the Oolite Group and the junction is irregular and the underlying limestones are pocketed for a short distance.

The irregular surface is filled by a conglomeratic bed, large rounded limestone boulders and pebbles are surrounded by yellow mudstone and the beds directly below the junction are dolomitized to the depth of a few feet. There is a slight discordancy of dip between the two groups at the base of the Tournaisian Main Limestone.

The microlithology of the massive light crystalline limestones at Pendine and Cloygen Quarry at the local top of the Tournaisian establishes that they have undergone strong recrystallization and the rock is often made up entirely of coarse clear interlocking sparry calcite crystals. In parts the original fabric can be seen to be dominantly an oolitic limestone. The ooliths are fairly uniform in size, darker in colour than the recrystallized calcite matrix.

Oolites are also developed below the mid-Dinantian unconformity along the North Crop of Breconshire (George 1954). A close lithological comparison is not possible between the oolite groups of the two areas because of strong recrystallization in the oolites of

Pembrokeshire. They are, however, similar in their cleaness of grain, even size of ooliths and the presence of occasional pellet rocks in the oolites. Moreover, occasional foraminifera are present in both oolite groups including plectogyrids and tournayellinids.

(b) Lateral variation in the Tournaisian Main Limestone.

Westwards from Pendine the Tournaisian Main Limestone is overstepped by the Visean. The Oolite Group is very poorly exposed inland; it appears near Greenbridge, just over a mile north-west of Pendine, where its thickness may be little more than 20 feet. It consists of less strongly recrystallized and darker oolites than those at Pendine. Microscopically, the ooliths are fairly uniform in size with abundant scattered crinoids and shell fragments, and rest in a matrix of clear recrystallized sparry calcite.

The Oolite Group may be thinly represented in a section exposed in a stream half a mile north-east of Marros Church (Strahan and others 1914, p.131), a half a mile north-west of Greenbridge; but at Gellihalog, five miles north-west of Pendine, the Tournaisian Main

Limestone is completely overstepped by the Viséan. The working quarry exposes Seminulan limestones resting on haematitized crinoidal limestones in the Lower Limestone Shales. Still further west, the Viséan completely oversteps Lower Limestone Shales and rests on to Lower Old Red Sandstone beyond Templeton, and on to Silurian rocks near Haverfordwest (Strahan and others 1914 pp.133-135).

(c) Age of the Oolite Group

The Oolite Group and the thin bedded crinoidal limestones directly below contain a rich Tournaisian brachiopod fauna (see faunal list, page 161), almost identical with the fauna recorded from Breconshire. Moreover, the fauna suggests a low Tournaisian Main Limestone age for these beds and is probably to be correlated with the Oolite Group of Breconshire which George (1954 p.297) has assigned to the *Zaphrentis* Zone. A low Tournaisian Main Limestone age for these beds in Pembrokeshire are also supported by the foraminifera in the great abundance of tournayellinids and plectogyrids (see fig. 17).

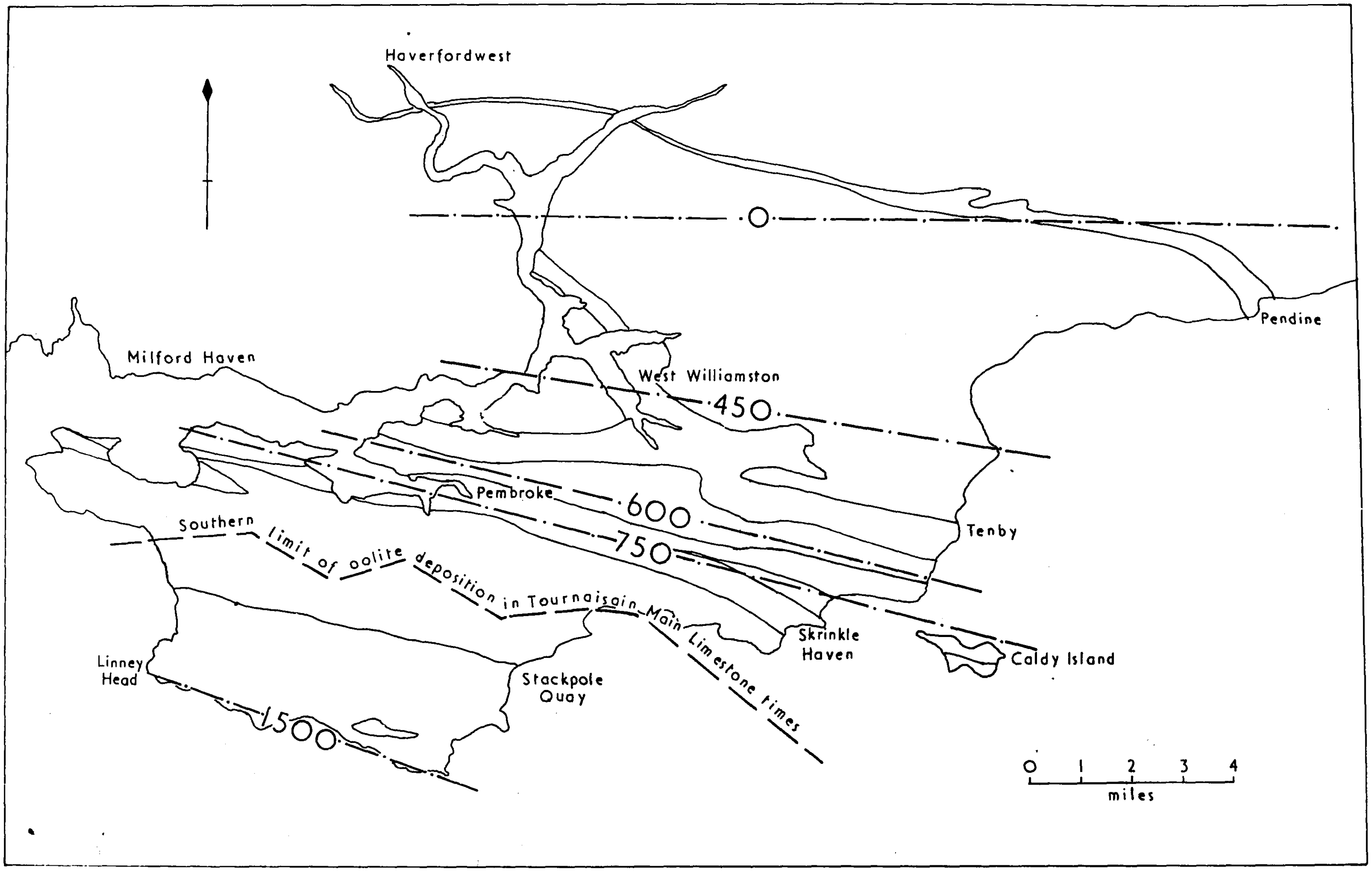
The unconformity at the base of the Oolite Group at Pendine appears to be slight and only locally developed since there is no evidence elsewhere along the North Crop, or indeed elsewhere in the S.W. Province, of a break at this level in the succession. On the other hand, the magnitude of the unconformity cannot be accurately determined and it may have more important structural and palaeogeographical significance.

5. Conditions of deposition of the Tournaisian Main Limestone in Pembrokeshire.

George (1958 pp.246-251) has already described the conditions of deposition and lateral variation across the depositional basin in the S.W. Province in the Tournaisian Main Limestone. This account presents the evidence from Pembrokeshire in greater detail.

It has been indicated in the Tournaisian that sedimentation though tending to a uniformity of facies and thickness along the structural (and depositional) strike displays sharp changes across the Armorican folds. There is but scanty evidence of Tournaisian shore-lines in Pembrokeshire, for the Tournaisian seas extended northwards beyond the limits of the present residual

Fig. 9 Map showing approximate isopachs (in feet) of the Tournaisian Main Limestone rocks.


Haverfordwest
Milford Haven
West Williamston
Pendine
450
0
600
750
1500
Pembroke
Tenby
Southern limit of oolite deposition in Tournaisain Main Limestone times
Skrinkle Haven
Caldy Island
Linney Head
Stackpole Quay
0 1 2 3 4
miles

outcrops. However, the pre-Tournaisian shore-line may be accurately placed along the line of the Ritec fault where Tournaisian rocks overstep the Upper Old Red Sandstone to rest, with littoral sediments at the base on Lower Old Red Sandstone. The Ritec fault continued to control sedimentation at intervals during the evolution of the depositional shelf.

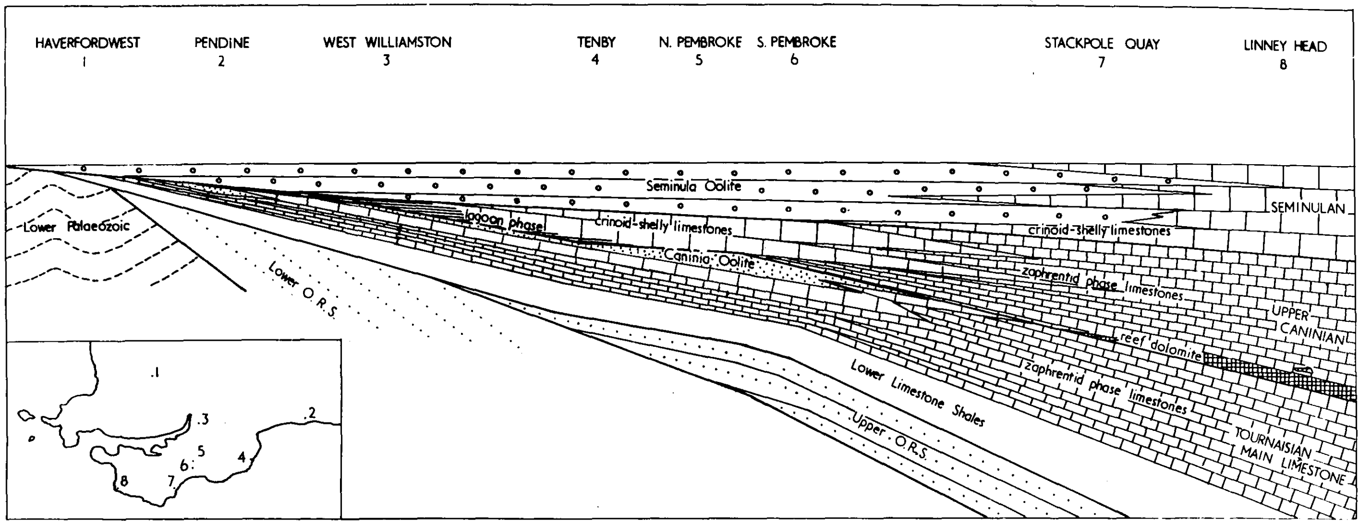
The northward thinning of the Tournaisian Main Limestone in Pembrokeshire has already been illustrated and it was shown that in the northern outcrops it was accentuated by Visean overstep along the borders of the fluctuating St. George's landmass. The northward attenuation is not constant (see fig.9) - a fact which points to differential subsidence on the depositional shelf. The borders of St.George's Land subsided at a slower rate than the seaward slopes of the shelf. As a result, there is a rapid diminution in thickness of sediments between the Bosherston and the Pembroke outcrops, becoming more gradual northwards.

Accompanying this northward attenuation there were widespread facies changes (see fig.10). Over the greater part of Pembrokeshire the Lower Tournaisian Main Limestone belongs essentially to a "zaphrentid phase". The sediments display dominantly a rhythmical succession of fine-grained calcarenites and calcareous mudstones and shales. The limestones are made up mainly of organic remains and fine terrigeneous muds. They are generally unsorted and show much evidence of flushing, shell-banking and current-variability. Locally there is evidence of sliding and slumping, usually on a small scale. Small scale slumps are particularly well seen in the lower part of the Tournaisian Main Limestone of the Pembroke Syncline and associated Angle Syncline. The interbedded mudstones reflect periodic increases in the influx of mud. The terrigenous muds were probably derived in part directly from the northern landmass and a part may have been derived from the reworking of the sediments in the littoral zone fringing St.George's Land, the finer muds being swept seawards. Also it is not unlikely that some of the muds may have a southerly source.

Along the North Crop of Pembrokeshire in the lower part of the Tournaisian Main Limestone oolites are developed in the succession. The oolites were deposited in extremely shallow agitated seas in which there was strong evaporation conditions. The deposits represent the first evidence of slight regional uplift on the flanks of St. George's Land. Emergence probably occurred at Pendine as seen by the break in the succession at the base of the Oolite Group, though as already mentioned, it may have more widespread palaeogeographical significance,

The evidence in Pembrokeshire confirms the palaeogeographical picture envisaged by George (1958, pp.249-251) of shallow water conditions gradually extending southwards in the Tournaisian Main Limestone times with the uplift of the coastal flats. However, it would appear that in Pembrokeshire oolite sedimentation was restricted to the fringes of St. George's Land in early Tournaisian Main Limestone times. The highly saline flats were flanked on the seaward side by winnowed crinoid and shell banks which delimited the coastal flats from the muddy waters further south. It

Fig. 10 Composite approximately north-south section across Pembrokeshire to illustrate changes of facies in the Tournaisian and lower Viséan rocks. The positions of the Pre-Tournaisian, Pre-Viséan and Pre-Seminulan shores are along the line of the Ritec fault between Tenby (4) and West Williamston (3) outcrops.


HAVERFORDWEST
1
PENDINE
2
WEST WILLIAMSTON
3
TENBY
4
N. PEMBROKE
5
S. PEMBROKE
6
STACKPOLE QUAY
7
LINNEY HEAD
8
Seminula Oolite
SEMINULAN
lagoon phase
crinoid-shelly limestones
crinoid-shelly limestones
Lower Palaeozoic
Caninia Oolite
zaphrentid phase limestones
UPPER CANINIAN
Lower O.R.S.
reef dolomite
zaphrentid phase limestones
Lower Limestone Shales
TOURNAISIAN MAIN LIMESTONE
Upper O.R.S.

was not until later Tournaisian times that oolitic sedimentation extended southwards into the West Williamston outcrop and Tenby and Pembroke Synclines. Oolites are not developed until the upper part of the Tournaisian in these outcrops. They extended southwards across the banks of shell and crinoid debris. Thick oolites are developed at two levels in the Upper Tournaisian Main Limestone in the southern limb of the Pembroke Syncline showing the migration was pulsatory. The southern limit of oolite migration lay between the Pembroke and Bosherston outcrops in the Upper Tournaisian times (see fig.9). The oolites reflect the onset of mid-Dinantian movements which finally brought Tournaisian sedimentation to a close.

IV SUCCESSION AND LATERAL VARIATION IN THE UPPER CANINIA ZONE OF PEMBROKESHIRE

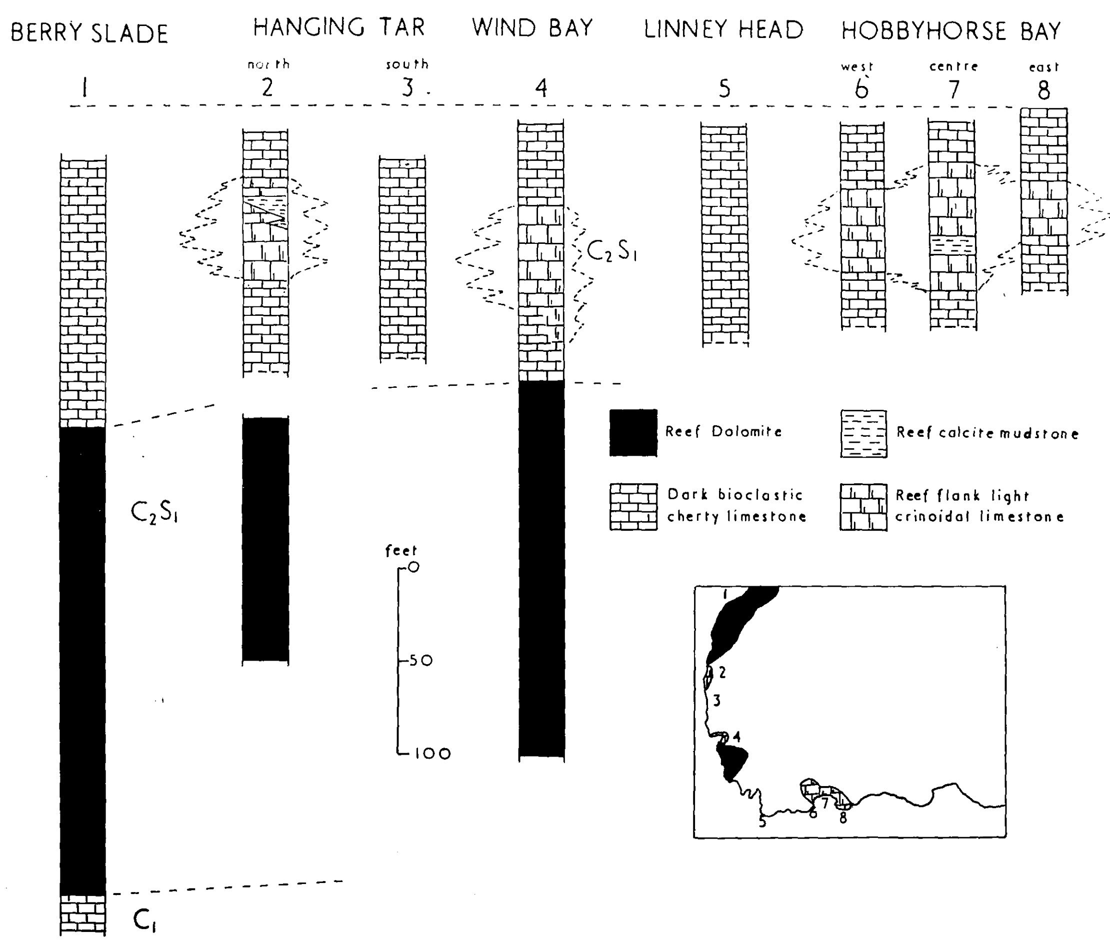
1. Bosherston Outcrop

The thickness of the Upper *Caninia* Zone in the Linney Head area is approximately 1,500 feet and includes at the base reef limestones. In the eastern part of the Bosherston outcrop the Upper *Caninia* Zone reappears at Stackpole Quay in the highly folded and faulted coastal section (see fig.4). The rocks at Stackpole Quay are similar in facies to those seen at Linney Head, Dixon's groups being recognized in both areas (1921, pp 126-134, 139-142). Each group thins eastwards, and it is evident that the bathymetric lines of the depositional basin in the south of Pembrokeshire would run a little south of east. The thickness of the Zone at Stackpole Quay is probably of the order of 1000 feet (see fig.14).

(a) Reef limestones

The reef, first described by Dixon, is a complex structure in its main (and dolomitized) development. It appears, from its uniformity of both thickness and lithology from Blucks Pool to Wind Bay (a distance of

Fig. 11 Comparative section of the basal Viséan rocks between Berry Slade and Hobbyhorse Bay.



BERRY SLADE
HANGING TAR
WIND BAY
LINNEY HEAD
HOBBYHORSE BAY
north
south
west
centre
east
1
2
3
4
5
6
7
8
C_2S_1
C_2S_1
C_1
feet
0
50
100
Reef Dolomite
Reef calcite mudstone
Dark bioclastic cherty limestone
Reef flank light crinoidal limestone

nearly a mile), to be a low lenticular or sheet-like growth and reappears apparently as a continuous structure ten miles to the east at Stackpole Quay. It is accompanied at a slightly higher horizon, however, by a series of much smaller reefs, in the form of patch reefs, which in being undolomitized and in displaying their relationships with the flanking bedded limestones, reveal conditions of formation like those described elsewhere in both British and Belgian Waulsortian rocks.

The reef dolomite is at least 250 feet thick in the cliffs at Berry Slade and Wind Bay in the Linney Head area (see fig.11). It is visible in the inverted overthrust mass at Stackpole Quay where it is separated from the main outcrop of the Upper Caninia Zone by the southern boundary overthrust on the northern side of Middle Cove (see fig.4). Only 110 feet of reef dolomite may be seen at Stackpole Quay, the full thickness probably not being exposed because of minor thrusting.

The reef dolomite consists of pale dolomite and is without analogue elsewhere in the British S.W.Province.

It is massive except at the base and the top, and locally in the middle at Blucks Pool where the rocks in the reef are well-bedded (bed 4 of Dixon 1921 p.127). The bedded rocks are incompletely dolomitized and appear to be altered crinoidal limestones. In the massive rocks of the main part of the reef, however, dolomitization has completely obliterated the original constituents except for abundant weathered-out crinoid remains. Thin irregular breccias are also developed (Dixon 1921 pp 129 and 139) and consist of small fragments of dolomite in a matrix stained with haematite. They may be local representatives of apron or flank breccias commonly known as a product of shallow-water erosion in regions of Carboniferous and other reef growths in many parts of the world.

The microscopic structure of the reef dolomite has been fully described by Dixon. Thin sections reveal a mosaic of anhedral crystals of dolomite forming the bulk of the rock and in places seen as replacing the original calcite.

The base of the reef dolomite is exposed in Blucks

EXPLANATION OF PLATE V

a. Thin bedded "zaphrentid phase" limestones, Linney Head.

b. Thin bedded "zaphrentid phase" limestones, near the Wash.

a.

b.

EXPLANATION OF PLATE VI

a. Thin, irregularly bedded "zaphrentid phase" limestones with a large caninioid coral on the bedding plane. Hanging Tar.

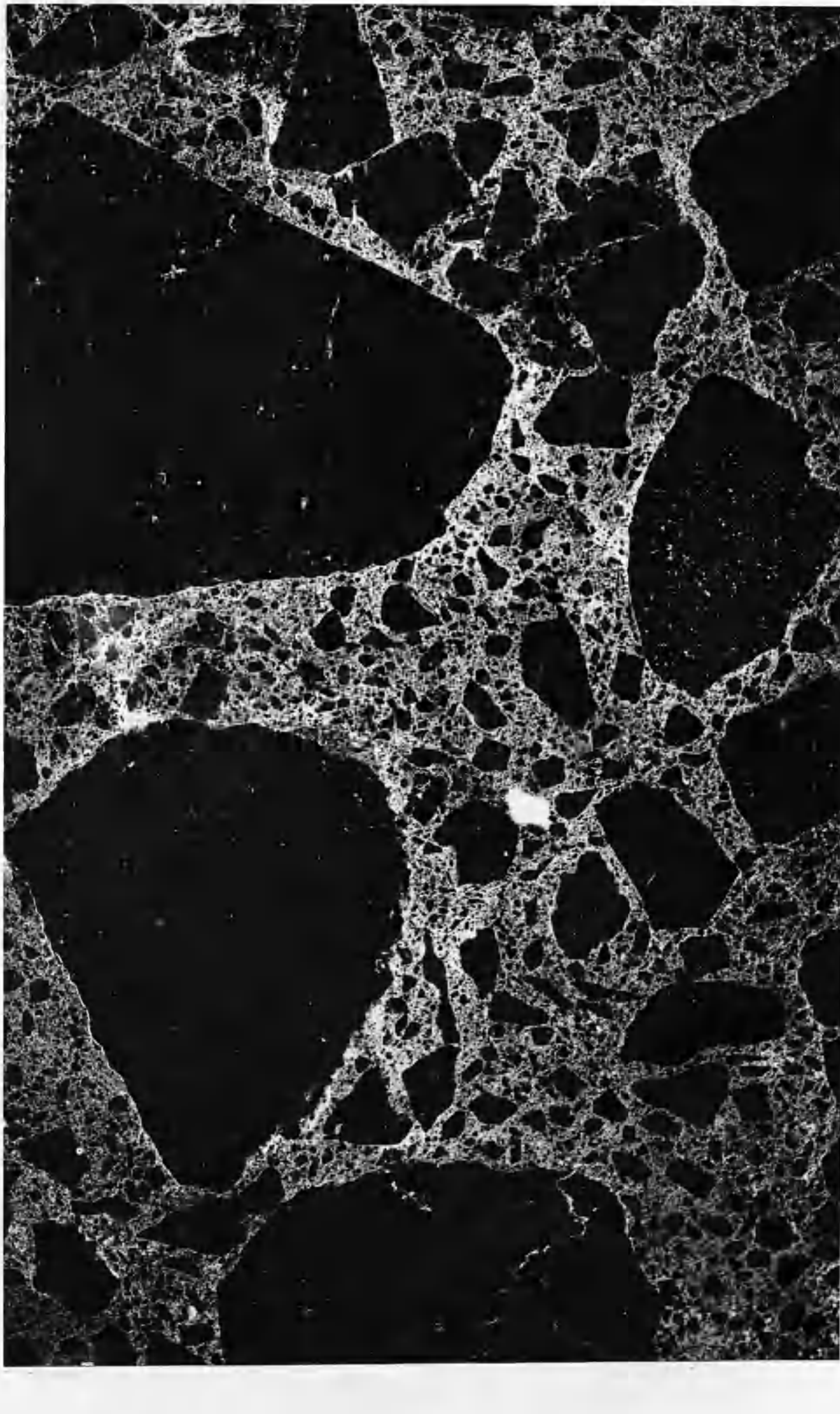
b. Colony of Lithostrotion, near the Wash.

a.

b.

EXPLANATION OF PLATE VII

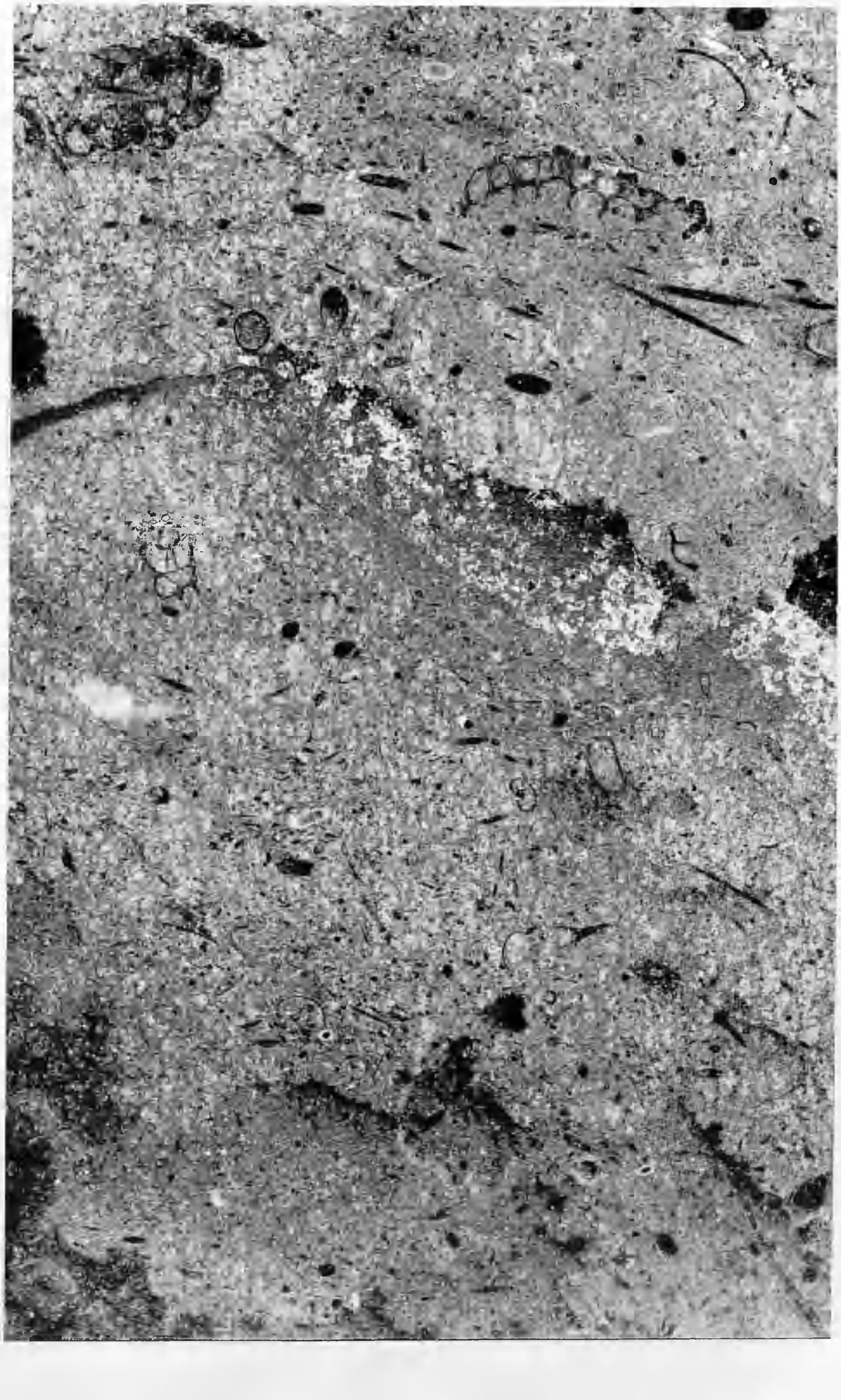
Reef breccia. Coarse breccia of angular fragments of dolomite set in a dark matrix strongly stained with haematite. Reef dolomite, Upper _Caninia_ Zone, Blucks Pool, Bosherston Outcrop. (x 18) The photograph is a negative.



EXPLANATION OF PLATE VIII

Reef limestone. Light mottled calcite-mud, rich in bioclastic fragments including bryozoa, crinoids, ostracods, calcispheres and foraminifera.

Patch reef, Upper *Caninia* Zone,
Hanging Tar, Bosherston Outcrop.
(x 18) The photograph is a negative.



Pool and at Stackpole Quay. In both areas it rests with a sharp junction on dark thin-bedded "zaphrentid phase" limestones of Tournaisian age. The lowest dolomites, making an abrupt appearance, are bedded for the first few feet with pale nodular cherts (contrasting with the dark nodular cherts in the beds below) but they pass quickly upwards into massive dolomite.

The relations with the enclosing "zaphrentid phase" limestones are best exposed at Hanging Tar and Wind Bay. The reef dolomite appears in the cliff in the anticlines at Wind Bay and Berry Slade (see fig.3). The junction with the enclosing bedded limestones is sharp and steep. The top of the reef is seen to dip at 45°- 55° - probably too great an angle to be the component of an original depositional dip. Not only is the junction sharp but there is clear evidence of a local erosion surface where the reef has a rubbly top. The reef debris at the junction is particularly well exposed in Wind Bay.

Patch reefs are developed above the main reefs at Hanging Tar, Wind Bay, and Hobbyhorse Bay (see figs.3 and 11) There is no sign of patch reefs above the reef dolomite at Stackpole Quay. At maximum development they vary in thickness from 70 to 100 feet.

The patch reefs are composed of light, massive, fine-grained calcite-mudstones, clear crystalline calcite in the form of irregular or ramifying veins being randomly developed throughout. Bryozoa are common but never obvious in the hand specimens. Locally the patch reefs are dolomitized (as at Hanging Tar) and in lithology become similar to the reef dolomite below.

Laterally the massive calcite-mudstones pass by alternations and inosculating wedges into flanking light grey, irregularly bedded, crinoidal limestones. In other instances, the massive reef limestones show tongues of reef-like calcite-mudstones becoming increasingly crinoidal laterally to become normal members of the series of bedded crinoidal limestones. Moreover, the lateral passage of the crinoidal limestones into the enclosing "zaphrentid phase" deposits is also seen to be gradual. Bedded light, coarse, crinoidal limestones pass into "zaphrentid phase" deposits with a deepening in colour and decrease in crinoidal debris, becoming finer grained and more argillaceous, with interbedded mudstones. A similar passage can be traced downward in the reefs. At the top of the reef, however, the junction with the overlying "zaphrentid phase" deposits is sharp. In Hobbyhorse Bay the top of the reef (the Hobbyhorse Limestone, bed 3, of Dixon 1921 p.131) is pocketed and infilled with a coarse organic debris in a yellow mudstone matrix. This suggests that the crests of the patch reefs (like the main reef) were within reach of wave erosion. The reef debris includes fish scales and brachiopod and crinoid remains. Elsewhere evidence of erosion is not so clearly seen but reef limestones are abruptly overlain, without transition, by the "zaphrentid phase" limestones.

Under the microscope, typical reef limestones are seen to be composed largely of sub-opaque, fine-grained, calcite mud that has undergone strong diagenetic recrystallization. It usually contains subordinate quantities of organic debris including crinoid remains, brachiopods, bryozoa, ostracods, calcispheres and foraminifera (see plate VIII). Unlike the associated "zaphrentid phase" limestones, foraminifera are not common in the reef. Bryozoa, not obvious in hand specimens, are abundant in thin section. Much of the fine-grained calcite-mud has a "clotted" appearance which suggests that it may be of algal origin, but recognizable algal tissue is extremely rare in the reef limestones. Irregularly distributed in the sections are coarsely recrystallized veins of clear calcite.

There is a marked contrast in fauna between the reefs and the enclosing "zaphrentid phase" limestones. The reefs are generally devoid of the abundant fauna associated with the enclosing sediments. Crinoids and bryozoa are the only abundant forms found in the reef. There are no rich pockets of brachiopods that are common in the Viséan reefs in other parts of Britain.

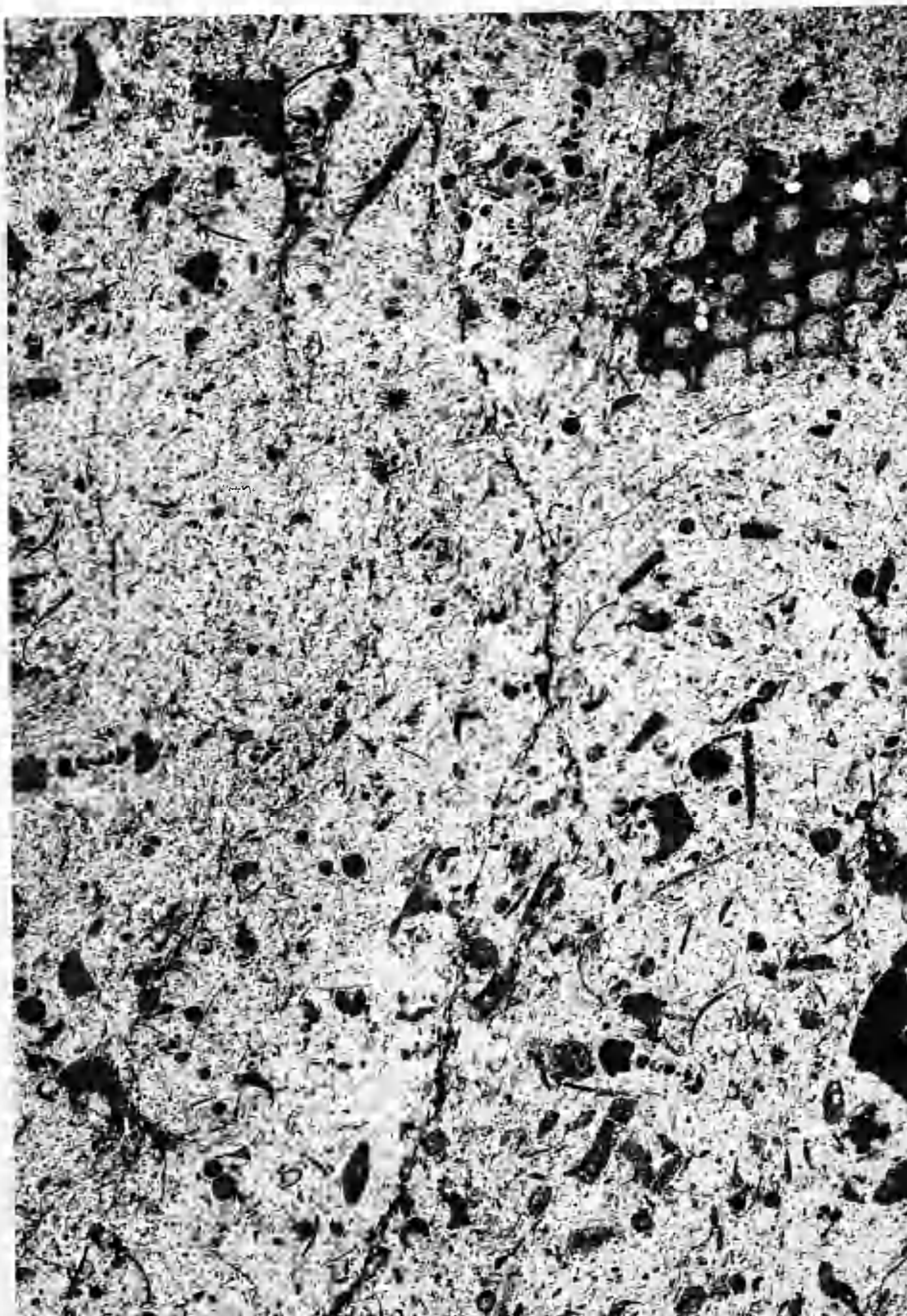
(b) Upper Caninia Zone "zaphrentid phase" limestones

"Zaphrentid phase" limestones broadly similar to those found in the Tournaisian Main Limestone continues above the reef upwards to the base of the *Seminula* Zone in the Bosherston outcrop. They characteristically consist of dark, fine-grained, bioclastic limestones with

EXPLANATION OF PLATE IX

Bioclastic limestone. Composed dominantly of organic fragments set in a dark fine-grained matrix. The organic fragments are mainly crinoids, shell fragments, echinoid spines, bryozoa and foraminifera. The foraminifera includes lituotubellids, archaeodiscids, Plectogyra, Endothyra, and earlandiids. Moreover, occasionally Tuberitina is to be found. The lithology is typical of "zaphrentid phase" limestones.

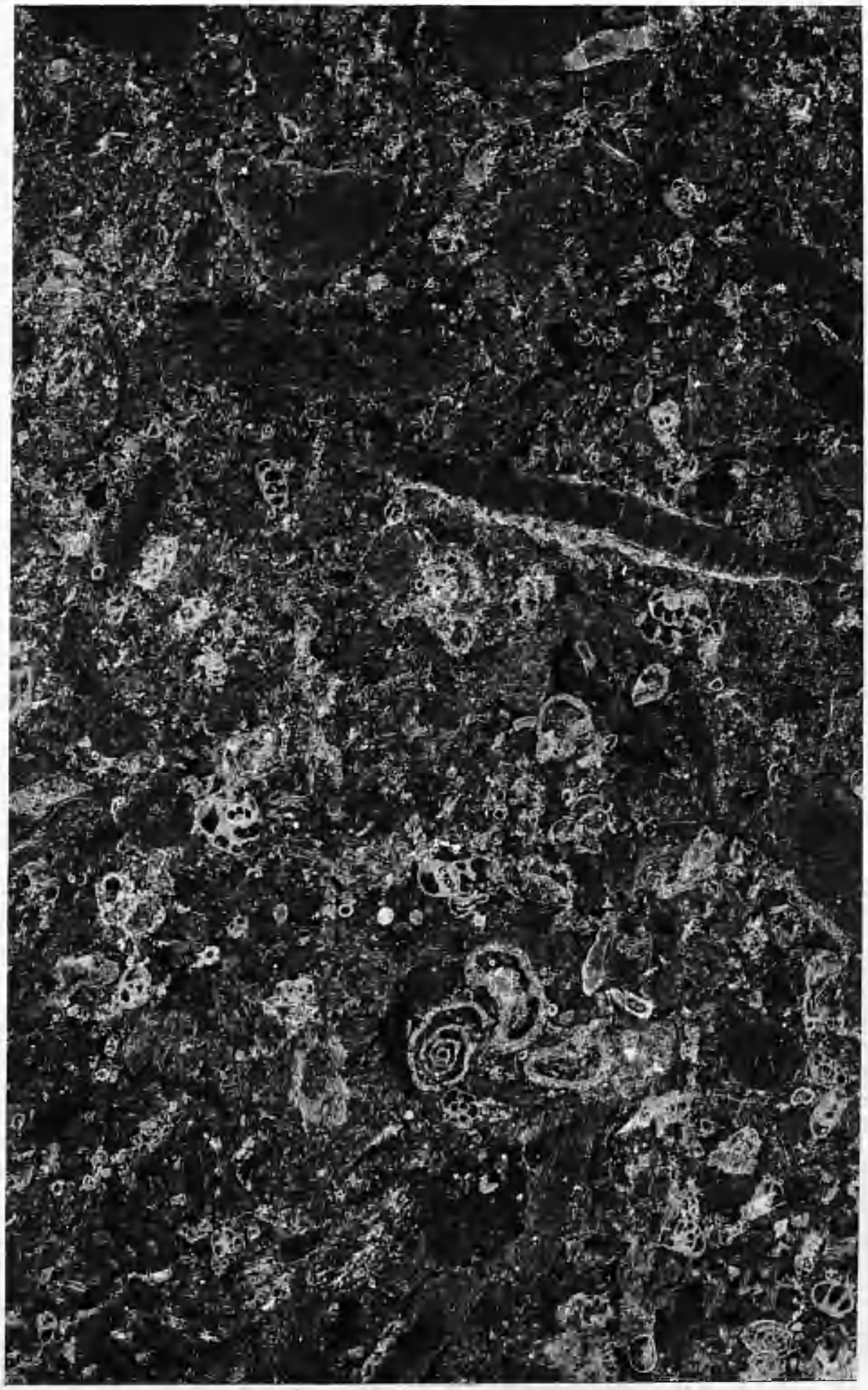
Upper Caninia Zone, Stackpole Quay. (x 18) The photograph is a negative.



EXPLANATION OF PLATE X

Bioclastic limestone. Composed of crinoid and brachiopod fragments in a dark fine-grained matrix. Foraminifera are abundant including lituotubellids, *Plectogyra*, *Endothyra*, *Endothyranopsis* and earlandiids.

"Zaphrentid phase" limestones, upper part of the Upper *Caninia* Zone, near the Wash. Bosherston Outcrop. (x 18) The photograph is a negative.



interbedded mudstones. Individual beds of limestone, a foot or less in thickness, can be traced for long distances in the cliffs, in some cases for a mile or more (see plate V). The junctions of the limestones and mudstones are abrupt, the mudstones are unlaminated, stained with iron, and less resistant to weathering. The limestones are rarely nodular, unlike the limestones of the Tournaisian Main Limestone in which the abundant nodules may be of secondary origin: perhaps significantly the Tournaisian mudstones are usually more calcareous and more richly organic.

Mudstones become thickly intercalated in the middle of the Upper Caninia Zone, one band being 40 feet thick. Fossils are particularly abundant and are often silicified and weather out in good preservation.

Occasional dolomites are sporadically developed throughout the sequence. Dark, nodular and concentrically-banded cherts are abundant at many levels.

Microscopically, the limestones are similar to those in the Tournaisian, being composed almost entirely of organic fragments set in a dark fine-grained matrix rich in argillaceous material (see plates IX & X). Shell fragments are common, and algae and bryzoa abound in the rock. Foraminifera are also extremely abundant.

Lighter, well-sorted, bioclastic limestones appear in the cliffs east of the Wash in the middle of Group 9 of Dixon (1921 p.121). These are more massive and coarser grained than the associated "zaphrentid phase" limestones without the interbedded mudstones. The following succession at the top of the Upper Caninia Zone (approximately equivalent to Group 9 of Dixon) occurs between the Wash and Stack Rocks:

4.	Massive light bioclastic limestones exposed at the top of Stack Rocks. Dixon recorded Davidsonina carbonaria at the base.	
3.	Dark "zaphrentid phase" limestones, thinly bedded and cherty with interbedded mudstones, forming the base of Stack Rocks.	80 feet
2.	More massive, light, coarse, bioclastic limestones	50 feet
1.	Thinly-bedded "zaphrentid phase" limestones with chert, forming the Wash.	

Under the microscope the limestones of bed 2 are seen to be dominantly composed of abraded crinoid and brachiopod fragments set in a dark sub-opaque matrix. Foraminifera are abundant, algae and bryozoa rare. The limestones, less muddy and better sorted than the "zaphrentid phase" limestones, contain, less obviously than the underlying reef, the sign of a change in the depositional environment of the area in early Viséan times and this may be looked upon as reflecting at a distance the onset of intra-Viséan movements.

Light bioclastic limestones reappear a little higher in the succession (bed 4) and mark the base of the Seminula Zone. The junction is abrupt and is exposed in the cliffs near Stack Rocks and the Green Bridge of Wales where Davidsonina carbonaria was recorded by Dixon (1921 pp 134 and 141).

Under the microscope, the basal Seminulan limestones are seen to be coarse-grained calcarenites rich in detrital fragments set in a dark fine matrix. Higher in the succession, they tend to be better sorted and strongly recrystallized, the detrital fragments being set in a clear, sparry, calcite matrix. Oolites are also interbedded in the succession: they are typically light and massive, comparable more with the Caninia Oolite than with the Seminulan Oolite of the Zone to the north. They are well-washed rocks, often containing a

EXPLANATION OF PLATE XI

"Lagoon phase" limestones resting on *Caninia* Oolite, South Sands, Tenby.

large proportion of shell debris and without the rich algal remains seen in the _Seminula_ Oolite to the north.

2. Pembroke and Tenby Synclines

Northwards from the Bosherston outcrop, the Upper _Caninia_ Zone thins and is represented by only 350-400 feet of limestones in the Pembroke and Tenby outcrops (see fig.14). However, the bioclastic facies of southernmost Pembrokeshire persists northwards and is developed in the greater part of the Zone (see Dixon 1921 pp 101-102, and 111-112).

Conditions appear to have been fairly uniform in the Pembroke and Tenby outcrops in Upper _Caninia_ Zone times since there is little variation in thickness and lithology when the beds are traced across the depositional strike. The junction with the underlying _Caninia_ Oolite is everywhere abrupt but there is no positive evidence for unconformity.

(a) "Lagoon phase" deposits

In the Tenby outcrop the basal Viséan sediments are 50-60 feet of "lagoon phase" deposits. They thin rapidly southwards and are absent at Giltar, a mile or so across

EXPLANATION OF PLATE XII

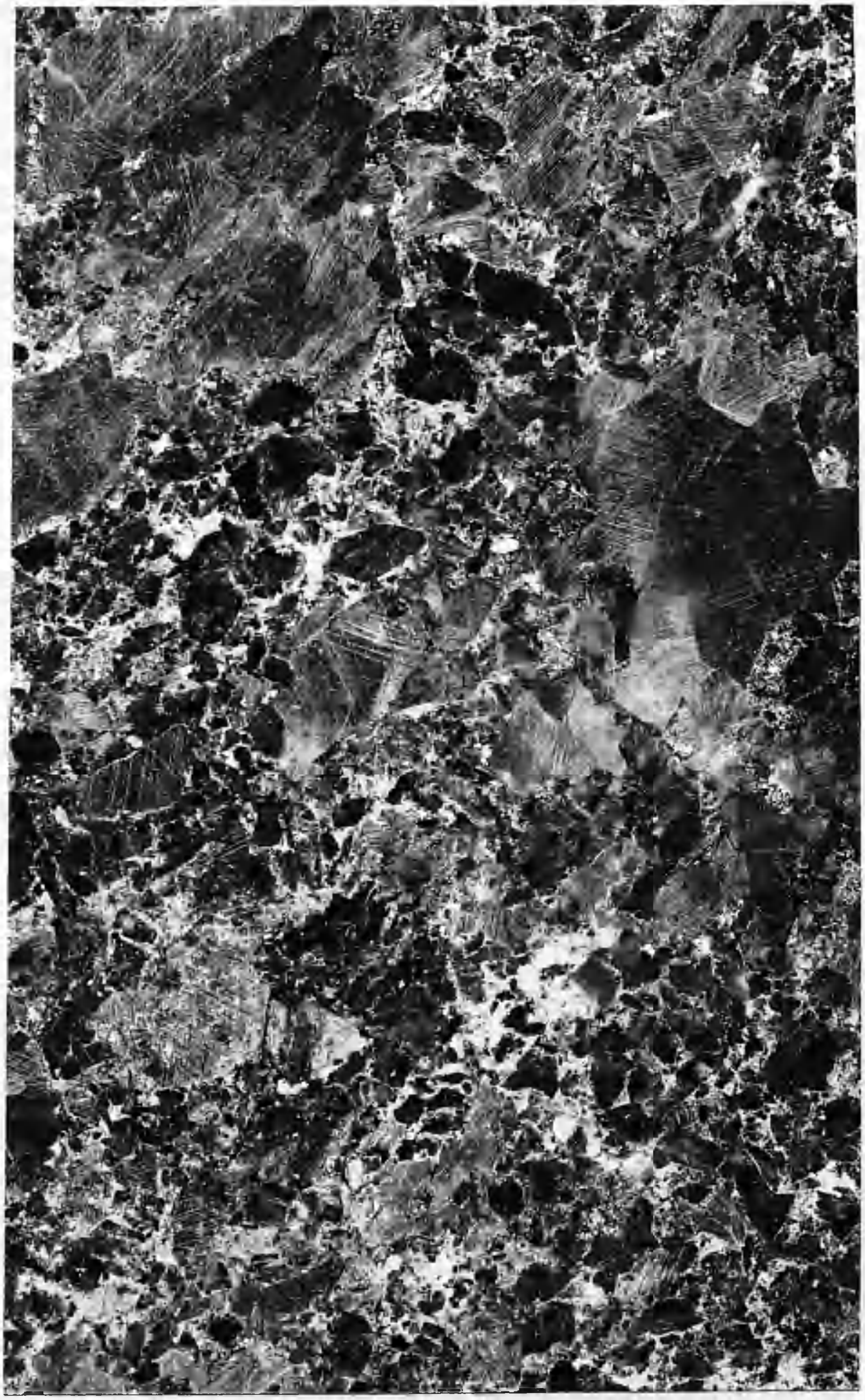
Ostracod-rich calcite-mudstone. Fine grained mottled calcite-mudstone with irregular distributed pockets of ostracods and calcispheres.

"Lagoon phase", base of the Upper Caninia Zone, Tenby South Sands. (x 8½) The photograph is a negative.

EXPLANATION OF PLATE XIII

Arenaceous crinoidal limestone. Composed mainly of large, secondary, highly twinned, calcite with organic crinoid and shell fragments. In addition, abundant angular quartzes are scattered throughout. The rock is stained with haematite.

"Lagoon phase", Upper _Caninia_ Zone, Tenby South Sands. (x 18) The photograph is a negative.



the depositional strike, on the northern limb of the Pembroke Syncline (see figs 6 and 15).

The "lagoon phase" deposits are a thin-bedded series of dark calcite-mudstones, extremely fine-grained and highly dolomitized, with thin shaly partings. They rest abruptly on an uneven surface of Caninia Oolite without evidence of erosion. The group appears to be without the thin pellet rocks, oolites, fine-breccias and bioclastic limestones described in the Gower (Dixon and Vaughan 1912 p.485). However, there is one thin band (only a few inches in thickness) of coarse haematitized crinoidal limestone in the middle of the group in the Tenby South Sands section.

Under the microscope the "lagoon phase" calcite mudstones are seen to be made up of very fine-grained "amorphous" calcite mud, often strongly mottled but without any obvious algal tissue (see plate XII). There is a high proportion of organic detritus scattered irregularly through the rock. Particularly abundant are ostracods, calcispheres and crinoid and brachiopod fragments. Moreover, a bed near the middle of the group yields abundant foraminifera including _Plectogyra_, _Endothyra_ and archaeodiscids, which establishes a Viséan age.

Clear patches of coarse, strongly-recrystallized calcite, surrounded by calcite mud, occur commonly in the calcilutites; George (1954 p.306) has suggested that these may represent the infillings of shrinkage cracks. Much of the rock is, however, highly dolomitized; made up in part of granular anhedral crystals and in part of well formed rhombs of dolomite,

The coarse, haematitized, crinoidal limestone in the middle of the group shows under the microscope a concentration of detrital fragments of quartz, with abundant coarse strained calcite crystals set in an iron-stained matrix. (see plate XIII)

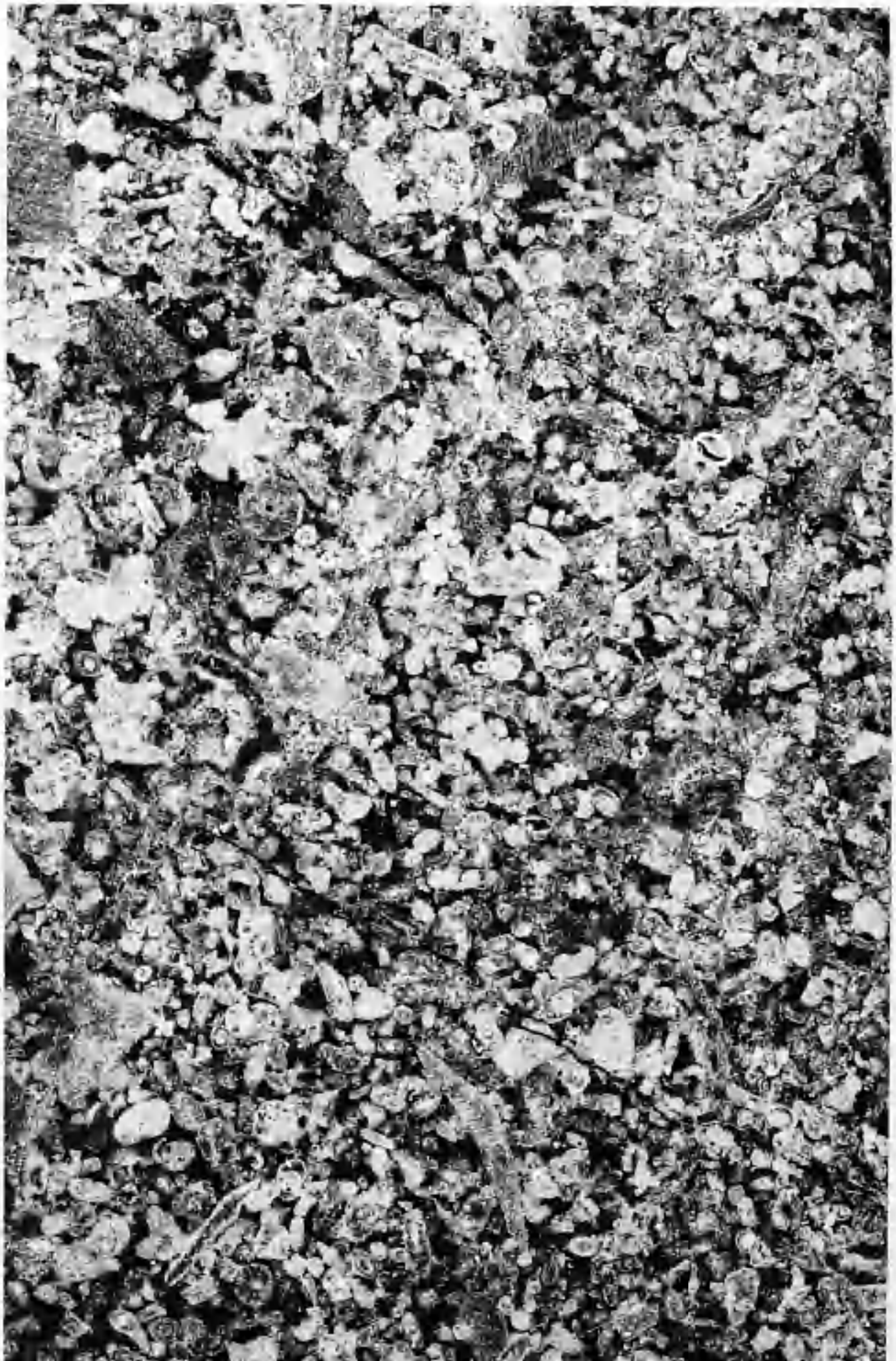
(b) "Standard" limestones

In contrast to the "lagoon phase" deposits, the succeeding beds are well-bedded light, winnowed, fossiliferous, bioclastic limestones of the Tenby outcrop. Moreover, they make up the greater part of the Upper _Caninia_ Zone in the Pembroke Syncline and contrast

EXPLANATION OF PLATE XIV

Bioclastic limestone. Composed mainly of intraclasts of rounded fragments of dark fine-grained calcite-mud. In addition there are common crinoid and shell fragments. Foraminifera is also abundant and includes plectogyrids and *Endothyra*.

Lower part of the Upper *Caninia* Zone, Black Mixen, Pembroke Syncline. (x 18) The photograph is a negative.



EXPLANATION OF PLATE XV

Bioclastic algal limestone. Composed largely of algae including filamentous algae, *Koninckopora*, and dasycladeous algae. Organic fragments are also fairly abundant including gasteropods, crinoids and brachiopods. Foraminifera are common, mainly plectogyrids, *Endothyra* and lituotubellids.

Top Upper *Caninia* Zone, Whitesheet Rock, Pembroke Syncline. (x 18)
The photograph is a negative.

markedly with the bioclastic limestone in the "zaphrentid phase" deposits of the Bosherston outcrop by being massive, coarse-grained, well-sorted limestones, devoid of chert and interbedded mudstones.

Under the microscope they are seen to consist dominantly of well-rounded fragments in a matrix of mainly a pure sparry cement. Many of the fragments are intraclasts[2] which are predominantly composed of fine-grained calcite-mud which in many cases contain included shell fragments (see plate XIV). The shell fragments include brachiopods, crinoids, gasteropods, abundant foraminifera, algae and to a lesser extent bryozoa. The intraclast fragments are in sharp contact with the matrix and show evidence of reworking. Small irregular pellets are scattered through the matrix and are made up of dark structureless calcite-mud which may be intraclasts as indicated above or alternatively may be faecal in origin.

[2] Intraclasts - see Folk, R.L. 1959 Practical petrographic classification of limestones. Bull. Assoc. of Petrol. Geol. 43 pp 4-6.

(c) Algal limestones

Interbedded at several horizons in the bioclastic limestones are thin-bedded, dark, algal limestones with shaly partings. They are particularly common at the base, middle and top of the Upper Caninia Zone (Groups 1, 3 and 5 of Dixon 1921 p.101) in the Pembroke Syncline and are easily picked out in the succession by their thin-bedded nature and lesser resistance to weathering. The limestones are usually selectively dolomitized and contain abundant gasteropods and nests of calcite and dolomite.

In thin section they are composed dominantly of dark, fine-grained calcite-mud, particularly rich in algal tissue (see plate XV). The algae include abundant Koninckopora, and spongiostromatoid and dasycladaceous algae. The dark calcite-muds are often "clotted" in appearance and reveal stages of disintegration of obvious algal tissue. Organic fragments are also fairly abundant. Scattered throughout are recrystallized patches of clear coarse calcite.

The algal limestones higher in the Upper Caninia

Zone are distinguished from the "lagoon phase" deposits in having a fairly abundant fauna. Detrital fragments of crinoids and brachiopods are common and foraminifera occur throughout.

(d) Junction of the Upper Caninia and Seminula Zones

The top of the Upper *Caninia* Zone is abruptly defined in the Pembroke and Tenby Synclines by the incoming of dark thick oolites and by the occurrence of a faunal change (see p. 99).

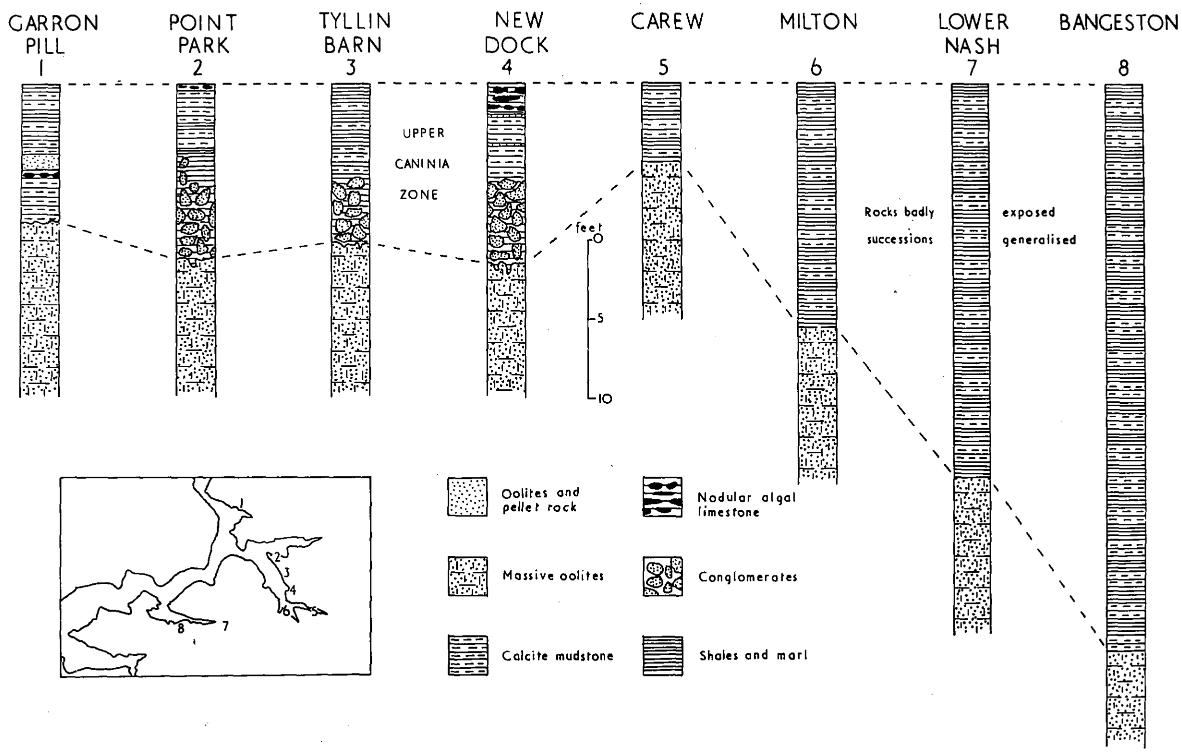
In the southern limb of the Pembroke Syncline and the eastern part of the northern limb of the fold (as at Giltar Point), the junction is readily identified where thin-bedded algal limestones are overlain by thick bedded oolites containing *Davidsonina carbonaria*. The junction is sharp without apparent unconformity. In the western part of the northern limb of the Pembroke Syncline (as at Catshole Quarry, Pembroke) and in the Tenby outcrop, the junction is less readily recognized but it is still sharp and clearly defined, again by the replacement of the well-bedded, coarse, bioclastic limestones of the Upper *Caninia* Zone by the dark thick oolites of the _Seminula_ Zone.

The Seminulan oolites are well-bedded dark rocks with interbedded algal limestones and thin shaly partings. Unlike the _Caninia_ Oolite it contains a fairly abundant fauna, foraminifera being particularly common. In thin section the oolites are composed of dark uniform ooliths, showing marked concentric banding (see plate XXII). The cores of the ooliths are commonly shell fragments and foraminifera. Also scattered throughout the rock are occasional shell fragments, particularly of crinoids and brachiopods. Algae are abundant and include _Koninckopora_, _Ortonella_, _Girvanella_ and spongiostromids. The matrix is made up of a coarse recrystallized calcite.

3. _West Williamston Outcrop_

The Visean succession in the West Williamston outcrop was described by Dixon (in Strahan and others 1914, pp 137-142, 147-148) as an apparently conformable but attenuated sequence, though locally at West Williamston a slight break was recorded at the base of the Upper _Caninia_ Zone (see fig.13). A revised

Fig. 12 Comparative section of the Upper _Caninia_ Zone in the West Williamston outcrop between Carron Pill and Bangeston.


GARRON PILL 1
POINT PARK 2
TYLLIN BARN 3
NEW DOCK 4
CAREW 5
MILTON 6
LOWER NASH 7
BANGESTON 8
UPPER CANINIA ZONE
feet
0
5
10
Rocks badly exposed
successions generalised
1
2
3
4
5
6
7
8
Oolites and pellet rock
Massive oolites
Calcite mudstone
Nodular algal limestone
Conglomerates
Shales and marl

EXPLANATION OF PLATE XVI

a. Conglomerate at the base of the "lagoon phase", Point Quarry, West Williamston outcrop.
Reproduction of Plate II from the Haverfordwest Memoir (Strahan & others 1914)

b. Pendine Conglomerate overlain by Seminulan limestones and underlain by the Oolite Group.
Pendine.

a.

b.

interpretation is that the Upper *Caninia* Zone is extremely thinly represented by 5-36 feet of "lagoon-phase" deposits, bounded above and below by unconformities.

(a) Succession and lateral variation of Upper *Caninia* Zone

The "lagoon phase" is well displayed on the east bank of the Carew River in the entrance docks of Point, Tilling Barns, Prinkly and New Dock quarries (see fig.7). It remains fairly constant at about 10 to 12 feet in thickness (see fig.12) and the following sequence is exposed in New Dock Entrance:-

5.	Massive dark oolites with thin bioclastic layers, overlain by three feet of dark argillaceous mudstones and shales. This is the base of the *Seminula* Zone	45' seen
4.	Rubbly-bedded fine-grained dark calcite mudstones with thin ribs of oolite	2'
3.	Massive, partly dolomitized, light calcite mudstones	4'
2.	Conglomeratic bed made up of rounded pebbles of oolitic limestones in a matrix of yellow mudstone. This is the base of the Upper *Caninia* Zone.	5'
1.	*Caninia* Oolite, massive and white-weathering.	

The erosion and pocketing of the *Caninia* Oolite, first described by Dixon (1914 p.141) is the positive evidence for the mid-Dinantian unconformity. The conglomerate is made up entirely of large rounded boulders derived from the underlying <u>Caninia</u> Oolite. The top of the oolite is extremely irregular and is "pocketed" for two to three feet. The conglomerate fills the irregularities and varies greatly in thickness from ten to four feet.

The calcite-mudstones overlying the conglomeratic bed consist of three to nine feet of mainly light calcite-mudstones with thin dark nodular algal limestones and irregular thin strings of oolites and pellet rocks. Interbedded in the series are thin dark shales and mudstones. The group is often highly dolomitized and gives a buff weathering surface to the limestones.

Although the "lagoon phase" retains its general lithology along most of the outcrop, there are considerable variations in detail, and individual beds are not readily followed for any great distance.

When the group is traced north and south from West Williamston, evidence of erosion at the base disappears. At Garron Pill to the north, 12 feet of calcite-mudstones is badly exposed in the banks of the estuary. The *Caninia* Oolite has an irregular top but conglomerate is absent at the base of the "lagoon phase". The calcite-mudstones are fairly massive, light in colour, with a thin oolite in the middle. There is sporadic dolomitization at the base.

South and south-west of West Williamston the "lagoon phase" is very poorly exposed. The variation in thickness is from 5 feet at Carew to 16 feet at Radford Pill, 25 feet at Lower Nash, and 36 feet at Bangeston on the foreshore of Cosheston Pill (see fig.12). There is, therefore, a slight thickening westwards. Again the conglomerate, or other evidence of erosion below the "lagoon phase", is completely absent, the group resting directly on an even surface of *Caninia* Oolite. The very abrupt junction, however, suggests the existence of a stratigraphical break.

Most of the rocks of the "lagoon phase" are calcilutites made up almost entirely of fine-grained "amorphous" calcite-mud, generally structureless but in part showing mottling which may be of algal origin

EXPLANATION OF PLATE XVII

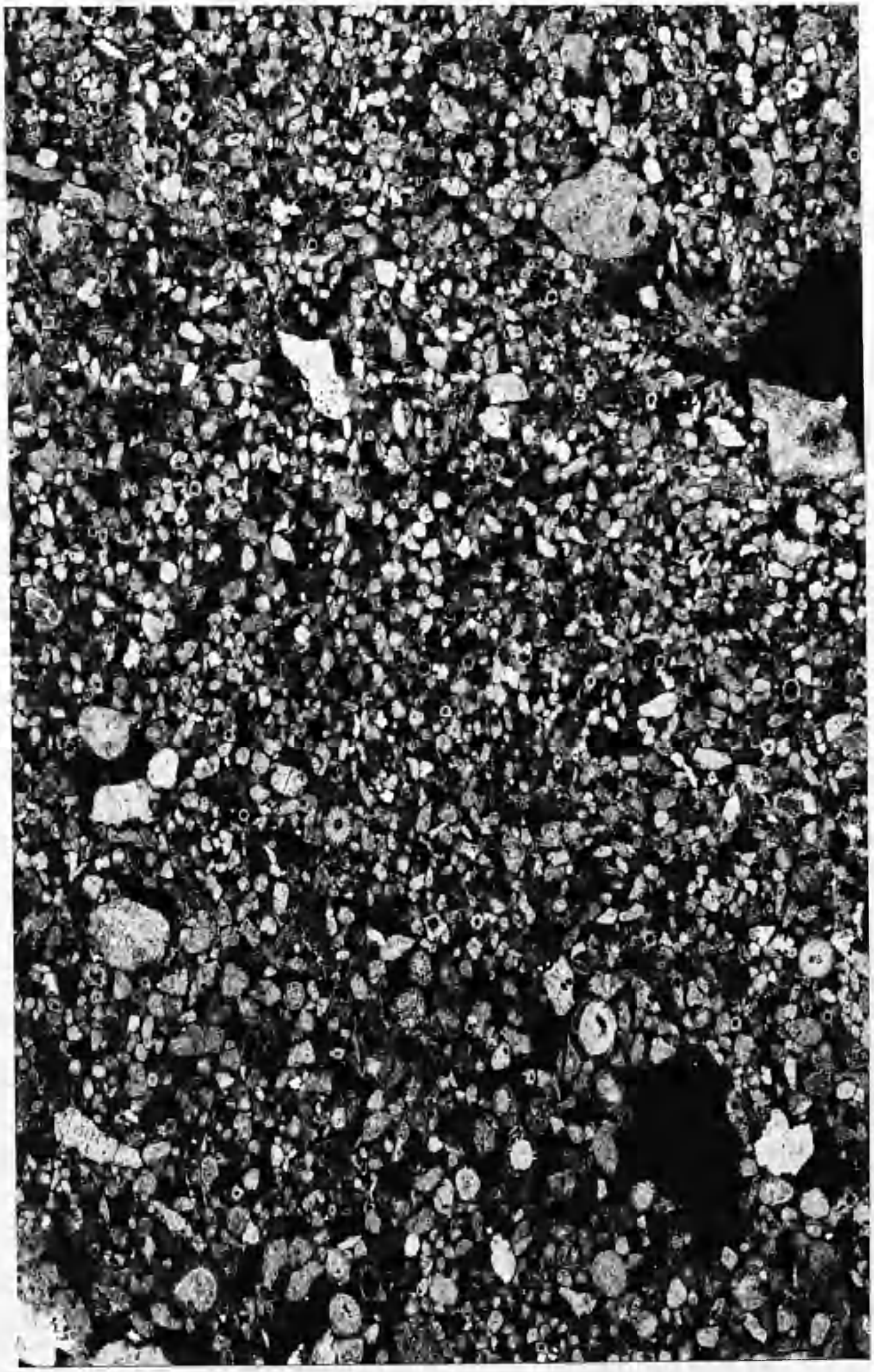
Oolitic limestone with a matrix of calcite-mud. The rock shows the complex association of unevenly distributed ooliths with a coating of dark calcite-mud set in a matrix of fine-grained calcite-mud. The ooliths show both concentric and radial structures. They are not always rounded and uniform in shape but take up the shape of the core. The cores are often crinoid and shell fragments or rounded calcite-mud pellets. Moreover, many of the cores are composite, some of the detrital fragments having a coating of calcite-mud which in turn are enclosed by the oolitic shell. The ooliths themselves are surrounded by a prominent dark, often concentric, coating of calcite-mud. The calcite-mud matrix is in part recrystallized but in other parts it is composed of calcite-mud which is often mottled and probably of algal origin. Occasional algal threads (probably _Girvanella_) and Spongiostromoid structures are to be seen.

The "lagoon phase", the Upper _Caninia_ Zone, New Dock Quarry, West Williamston. (x 8) The photograph is a negative.

EXPLANATION OF PLATE XVIII

Pellet rock. Rock composed mainly of small, fine-grained, pellets of calcite-mud in a clear, recrystallized matrix. In addition, irregular patches of calcite-mud are still preserved in the matrix. Scattered throughout occasional well rounded ooliths showing both concentric and radial structure and derived limestone fragments. Also abundant angular quartzes are to be seen.

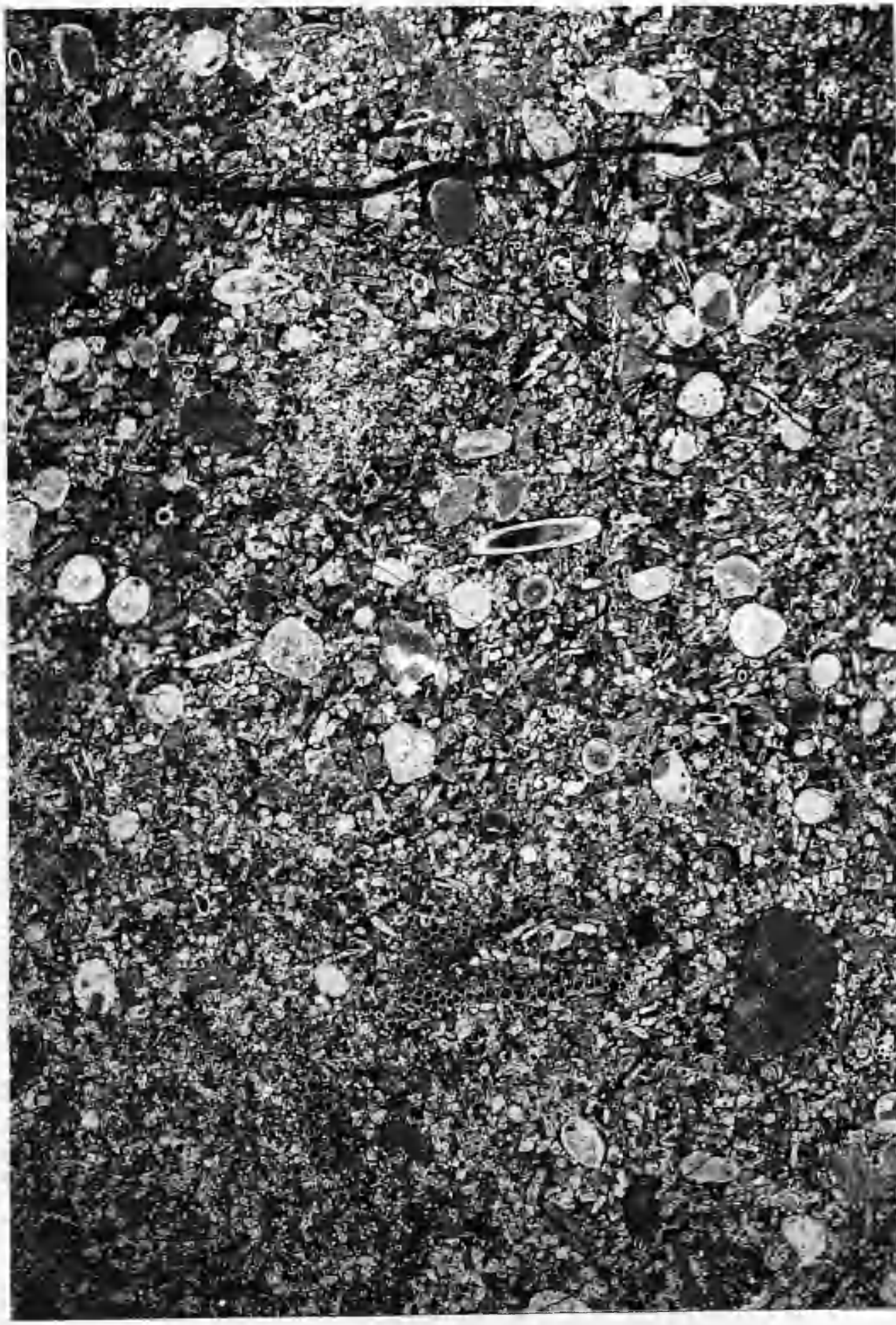
"Lagoon phase" Upper *Caninia* Zone, Garron Pill, West Williamston Outcrop. (x 10) The photograph is a negative.



EXPLANATION OF PLATE XIX

Pellet rock. Composed dominantly of pellets of dark calcite-mud rich in organic fragments. Crinoid brachiopod fragments are common. Foraminifera are abundant and includes earlandiids, *Plectogyra* and *Endothyra*. The rock is particularly rich in algae, mainly *Koninckopora*.

Base of the *Seminula* Zone,
Bangeston, West Williamston.
(x 18) The photograph is a negative.



(though there is no obvious algal tissue). Scattered in the calcite-mudstones are irregular patches of recrystallized coarse calcite. Fossils include only ostracods and calcispheres which tend to be concentrated in thin layers, brachiopods, crinoids and polyzoans being unrepresented.

Occasional thin oolites and pellet rocks are interbedded in the calcite-mudstones. The ooliths are fairly even-grained, showing concentric layering and set in a dark calcite-mud matrix (see plate XVII). The ooliths are well formed and many have a core of calcispheres or small detrital fragments. The pellet rocks are composed dominantly of small uniform pellets of fine, subopaque, structureless, calcite-mud. They are probably of faecal origin, (George 1954 p.307). Small ooliths are also irregularly scattered amongst the pellet rocks together with detrital quartz grains (see plate XVIII).

(b) Age of the "lagoon phase" deposits

Fossils are absent from the group except for spirorbids, ostracods, calcispheres and occasional small lamellibranchs which give no indication of age.

Nevertheless, the Tournaisian-Viséan relationships along the North Crop in Breconshire leave little doubt that the Calcite Mudstone Group (the "lagoon phase" deposit) in Pembrokeshire may also be assigned to the Upper <u>Caninia</u> Zone. In the two areas the groups are closely comparable in lithology and both unconformably overlie the Tournaisian Main Limestone.

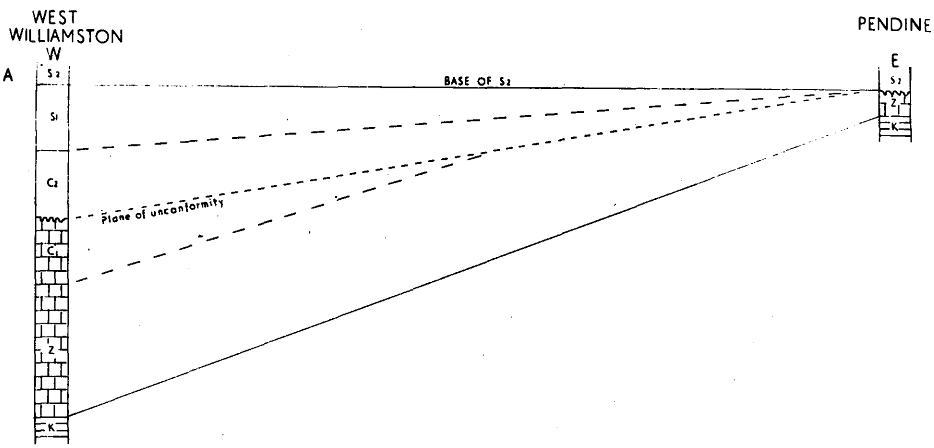
The junction of the "lagoon phase" deposits and overlying Seminulan limestones is everywhere abrupt and indicates a stratigraphical break. The thinning of the "lagoon phase" eastwards and northwards may be due to overstep at the base of the <u>Seminula</u> Zone. The Seminulan limestones are typically dark massive oolites with thin algal limestones and shales. The basal two to three inches is a fine-grained pellet rock with a clear calcite matrix (see plate XIX) and passes upwards into a coarse oolite with rich bioclastic layers. The oolites contain abundant foraminifera, algae and shell fragments and are closely comparable to the <u>Seminula</u> Oolite in the Pembroke and Tenby Synclines. The lowermost

Fig. 13 Diagrammatic section showing the relations between West Williamston and Pendine.

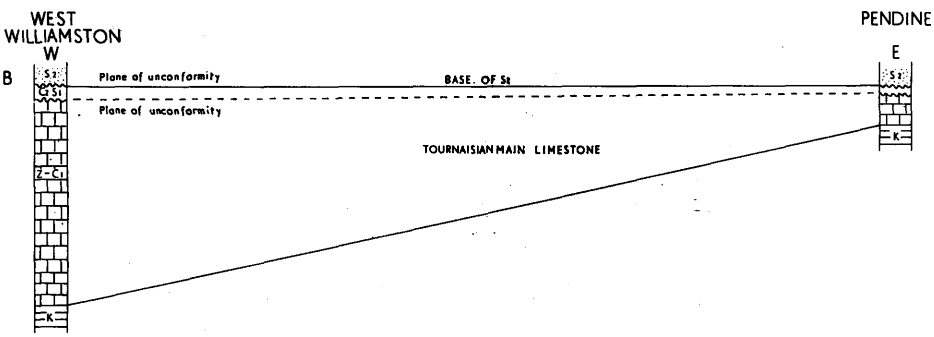
A. After Dixon (see Dixon and Vaughan 1912 fig.7 p. 527)

B. As interpreted by the author

A


WEST
WILLIAMSTON
W
PENDINE
E
BASE OF S2
Plane of unconformity
S2
S1
C2
C1
Z
K

B


WEST
WILLIAMSTON
W
PENDINE
E
Plane of unconformity
BASE. OF S2
Plane of unconformity
TOURNAISIAN MAIN LIMESTONE
S2
C2 S1
Z-C1
K

Seminulan limestones yield an abundant fauna (see faunal list page 157) which confirms a Seminula Zone age for these beds.

The two breaks demonstrated by George (1954) in Breconshire are thus shown to extend to the western outcrops of the S.W.Province.

4. North Crop of Pembrokeshire

Dixon (in Strahan and others, 1914 pp 129-135) described the rock relationships along the North Crop of Pembrokeshire but his description requires some emendation not only of the zonal sequence but also of the zonal discontinuities. The Upper Caninia Zone (S_1) was thought to be very variable above the plane of the mid-Dinantian unconformity; in places thickly developed and in other places absent, features which suggested deposition of the lower Visean on an uneven floor. East of Castle Ely, the Upper Caninia Zone (S_1) was thought to die out due to internal overlap eastwards, and at Pendine the Seminula Zone (S_2) was thought to lie directly on lower Tournaisian limestone with a thick conglomerate at the base.

(a) The Lower Viséan succession at Pendine

The Pendine sequence spectacularly illustrates the lower Viséan non-sequences. The succession is well exposed near Dolwen Point.

4.	Well-bedded, dark, oolitic limestones	
3.	Well-bedded, dark, algal limestones, nodular in the lower 2 feet, marking the base of the *Seminula* Zone	12'
2.	Pendine Conglomerate	
(c)	Dark conglomerate containing a large variety of pebbles and boulders	2' 3"
(b)	Thinly bedded calcite-mudstones, with thin interbedded mudstones, the limestones highly dolomitized	7'
(a)	Conglomeratic bed, consisting of pebbles of light recrystallized limestones filling the irregularities in the top of the underlying Tournaisian Main Limestone	7-8'
1.	Massive, highly-recrystallized oolitic limestones - the Oolite Group of the Tournaisian Main Limestone	58'

The top of the Oolite Group (bed 1) is seen with pockets several feet deep and the depressions filled with boulders derived from the underlying beds. The boulders are large, rounded and set in a clay matrix. The bedded calcite-mudstones (bed 2b) lie on the irregular surface of the underlying conglomerate and are steeply inclined (15^{o}) when compared with the gently dipping Seminulan limestones and Tournaisian limestones above and below (see plate XVI). Lying irregularly above the bedded calcite-mudstones is a dark coarse conglomerate (bed 2c); it is poorly sorted with a large variety of mixed pebbles and boulders and is readily distinguished from the lower conglomerate.

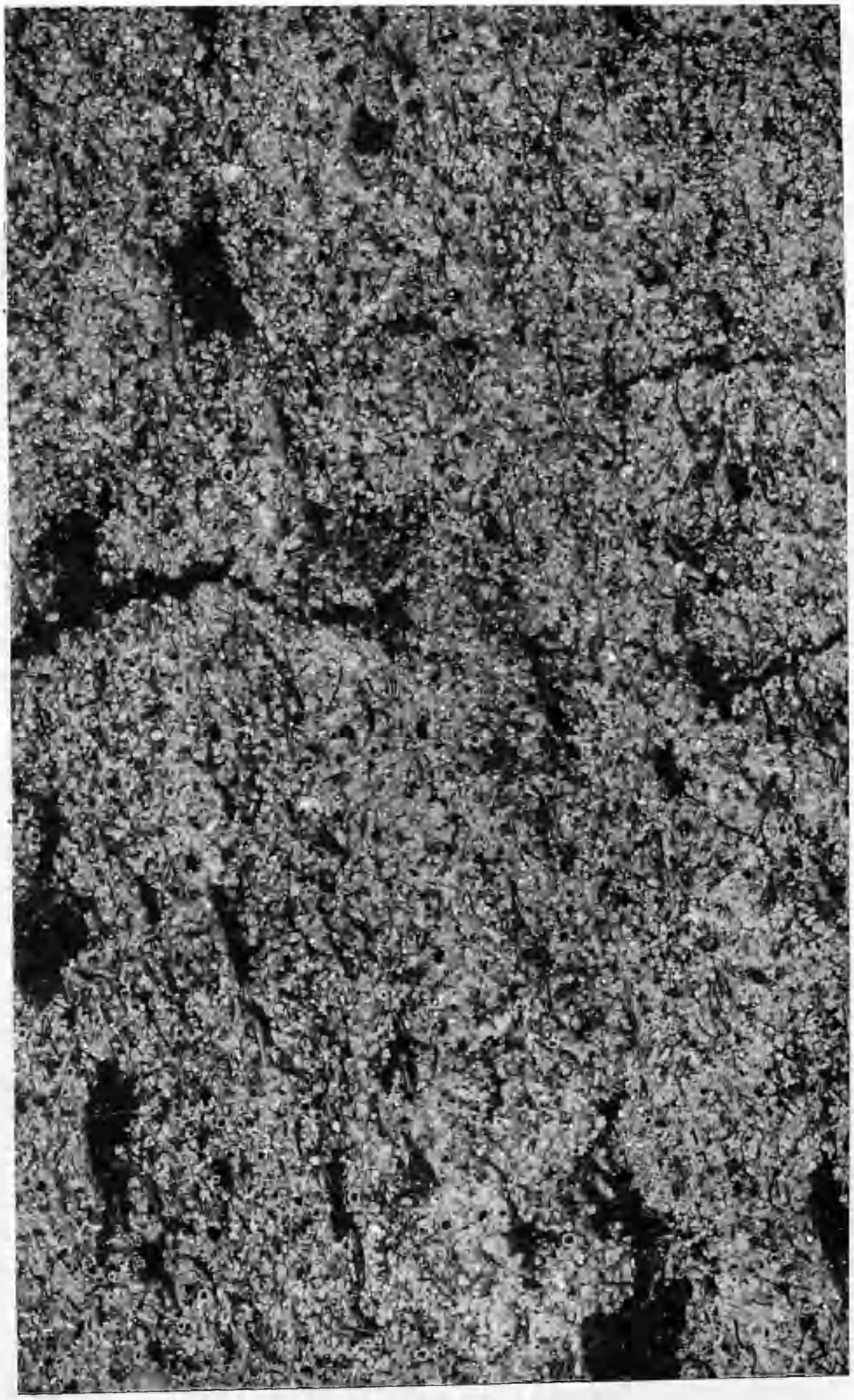
This peculiar rock group, collectively called the "Pendine Conglomerate" thins rapidly eastwards in the cliff; in 100 yards it is reduced to two to three feet in thickness and is represented entirely by a dark conglomerate identical with the upper conglomerate (bed 2c) in the section to the west and lying abruptly on the irregular, but not pocketed, surface of the Oolite Group.

The contact of the Seminulan limestones and the Pendine Conglomerate is abrupt, the upper conglomerate of the Pendine Conglomerate being overlain by dark rubbly algal limestones which become regularly bedded upwards and contain a rich gasteropod fauna. The algal limestones are in turn overlain by alternations of oolitic limestones, algal limestones and shales with

EXPLANATION OF PLATE XX

Pellet rock. The rock is composed dominantly of pellets of calcite-mud rich in ostracods and calcispheres. Irregularly distributed through the rock is patches of clear sparry calcite which may have been infillings of shrinkage cracks.

Pendine Conglomerate, Upper _Caninia_ Zone, Pendine. (x 18)
The photograph is a negative.

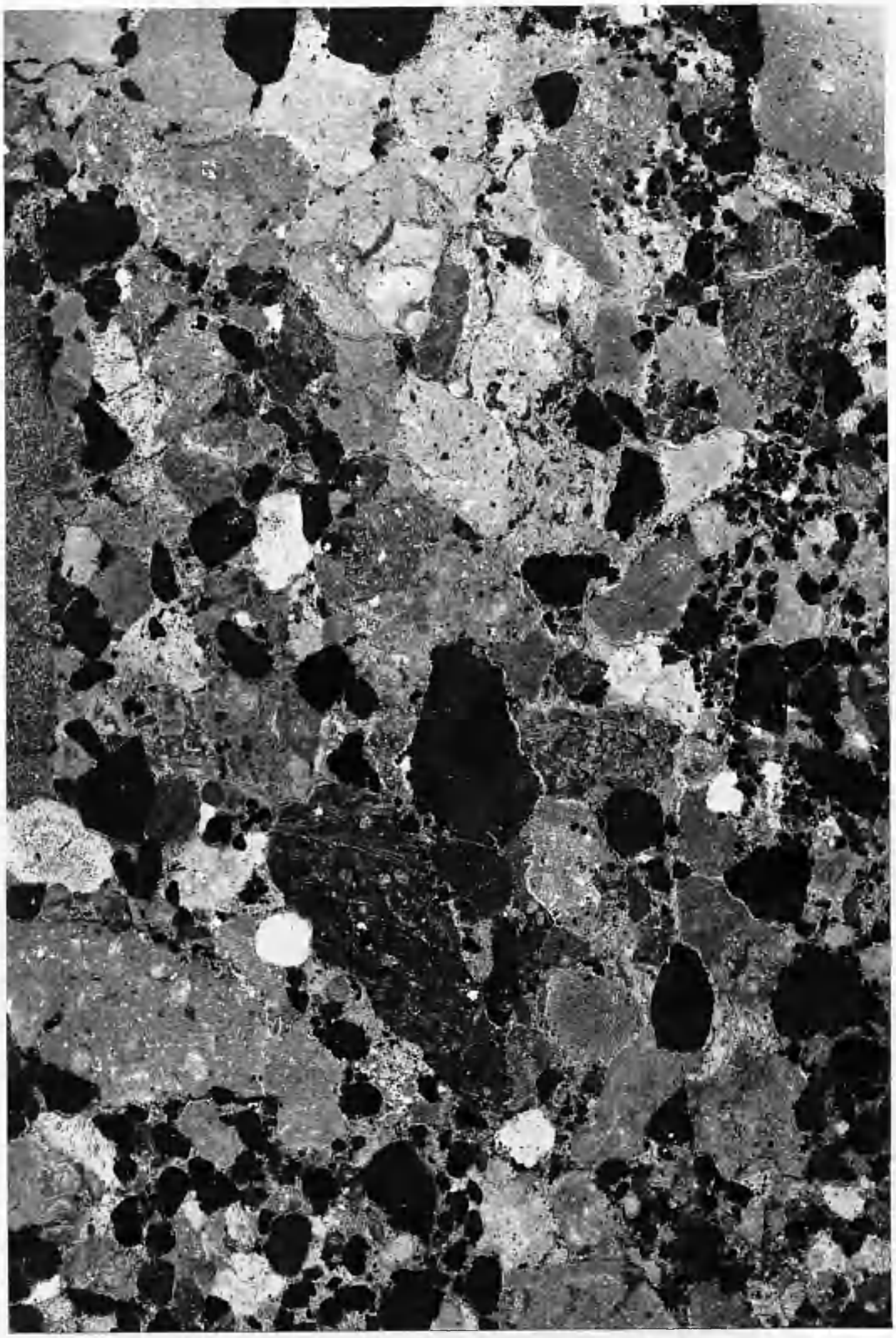


EXPLANATION OF PLATE XXI

Conglomerate composed largely of limestone pebbles, mainly oolites, calcite-mudstones, bioclastic limestones and fragments of algae (mainly _Ortonella_) with abundant angular quartzes set in a dark matrix.

(x 8) Pendine Conglomerate, Greenbridge.

(x 18) The photograph is a negative.



EXPLANATION OF PLATE XXII

Oolitic bioclastic limestone. Coarse oolitic limestone with pockets of finer oolites and abundant crinoid and shell fragments. Algae is abundant and the dominant form is Koninckopora. Many of the fragments are surrounded by a thin coating of dark calcite-mud. The shape of the oolith appears to be controlled by the core which are mainly shell and crinoid fragments. The matrix is clear, sparry calcite.

Base of Seminula Zone, Pendine.
(x 18) The photograph is a negative.

Davidsonina carbonaria and *Caninia cylindrica*. The beds directly above the Pendine Conglomerate are, therefore, of *Seminula* Zone age.

(b) Lithology of the Pendine Conglomerate

The calcite-mudstones of the Pendine Conglomerate are very similar to the basal Viséan calcite-mudstones at West Williamston. They consist of fine calcite-mud, in parts recrystallized, and often mottled in appearance, though there is no identifiable algal tissue in the rock. They include pellet rocks made up of grains of fine, dark, uniform calcite-mud with abundant ostracods and calcispheres (see plate XX).

The boulders in the lower conglomerate are all derived from the underlying Oolite Group. The upper conglomerate is more varied: it contains a varied collection of pebbles including haematitized crinoidal limestones, bioclastic limestones, pellet rocks and oolites. The pebbles are set in a dark sandy matrix (see plate XXI), containing abundant angular quartzes and heavy minerals including zircon, occasional rutile, and rare garnets and tourmaline. The heavy minerals are probably derived from the Old Red Sandstone.

Oolites are the most common constituent pebbles in the upper conglomerate and are identical with the limestones in the underlying Oolite Group. The crinoidal limestones are haematitized and contain abundant abraded fragments of crinoids, brachiopods and ostracods. Foraminifera in the pebbles confirm Tournaisian derivation. Ostracods are sufficiently abundant in some pebbles to constitute an ostracod limestone. Pellet rocks are also fairly common in the conglomerate and are made up of elongate grains of dark "structureless" calcite-mud. It is possible that the pellet rocks were derived from the Oolite Group or from the pellet rocks in the calcite-mudstones directly beneath the conglomerate. In addition, pebbles of algae - mainly Ortonella (see plate XXI) - are occasionally found.

(c) Lateral variation in the Pendine Conglomerate

The Pendine Conglomerate thins east and west of Pendine. At Cloygen Quarry, three and a half miles to the north-east, it is represented by six to seven feet of coarse conglomerate, similar to the lower conglomerate at Pendine, composed of boulders derived from the underlying Oolite Group, and fills the irregularities in the top of the Tournaisian Main Limestone. It is abruptly overlain by dark Seminulan algal limestones like the basal Seminulan beds at Pendine.

North-west of Pendine, the Pendine Conglomerate is poorly exposed and only thinly represented. Near Greenbridge, just over a mile north-west of Pendine, it is two to three feet in thickness, and is represented by a dark conglomerate similar to the upper conglomerate at Pendine. It directly overlies the Oolite Group, with an irregular junction between, and is in turn abruptly followed by dark Seminulan algal limestones. Further west from Greenbridge the <u>Seminula</u> Zone oversteps the Pendine Conglomerate to transgress ultimately the whole of the Tournaisian. In a stream section half a mile north-west of Greenbridge, the Pendine Conglomerate is absent, Seminulan limestones directly resting on the Oolite Group (Dixon in Strahan and others 1914 p.131). A similar relationship is seen at Blaencilcoed further west, where Seminulan limestones rest directly on a coarse haematitized crinoidal limestone in the Lower Limestone Shales, the Oolite Group having been completely eliminated.

The _Seminula_ Zone is the lowest Viséan exposed west of Greenbridge. The presence of the Upper _Caninia_ Zone (S_1) along the North Crop was made on the assumption that _Caninia cylindrica_ is diagnostic of this Zone, as cited by Vaughan (1905 pp 195 and 254). It is now known that _Caninia cylindrica_ continues up into the _Seminula_ Zone (see page 99 and George 1927 p.45).

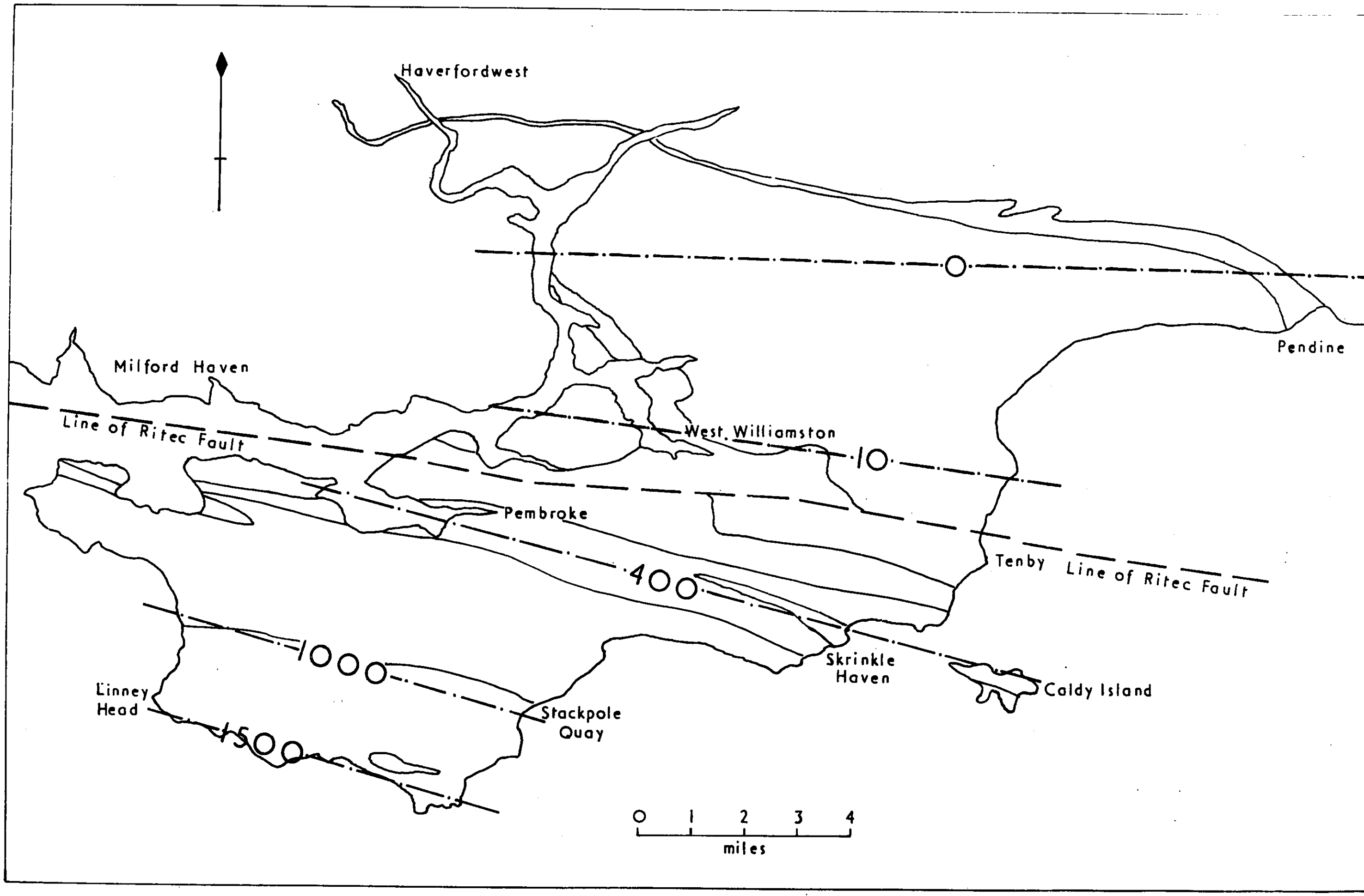
(d) _Age of the Pendine Conglomerate_

No fossils could be found in the matrix of the Pendine Conglomerate or in the calcite-mudstones (other than ostracods and calcispheres) to indicate an age for the deposit. There can be little doubt, however, that the Pendine Conglomerate belongs to the Upper _Caninia_ Zone, and is itself followed unconformably by the _Seminula_ Zone. Dixon's interpretation of the diachronous rise of "lagoon phase" deposits northwards, the Pendine Conglomerate being of basal Seminulan age, is probably too simple, for he did not appreciate the existence of the sub-Seminulan break. A comparison with Breconshire provides a close analogy between Seminulan overlap in South Wales and in Pembrokeshire, and simplifies and unifies lithological contrasts that thus extend over a great part of the southern flanks of St.George's Land.

5. <u>Conditions of deposition of the Upper Caninia Zone</u>

The mid-Dinantian movements brought Tournaisian sedimentation to a close in the areas north of the Tenby Syncline, while in south Pembrokeshire they produced a widespread palaeogeographical change reflected in the lithology of the early Viséan sediments. The main palaeogeographical control on Dinantian sedimentation in Pembrokeshire continued to be the massif of St. George's Land. The trend of the northern shoreline at the end of Tournaisian times appears to have been affected by the incipient growth of the Ritec fault (see figs.10 and 14). North of the Ritec fault the deposits were uplifted and eroded. Emergence was greatest to the north and approximately 400 feet of Tournaisian Main Limestone was removed in the six miles between Tenby and Pendine (George 1958 p.259). Despite

Fig. 14 Map showing approximate isopachs (in feet) of the Upper *Caninia* Zone.



Haverfordwest
Milford Haven
Line of Ritec Fault
West Williamston
10
Pendine
Pembroke
400
Tenby
Line of Ritec Fault
1000
Skrinkle Haven
Caldy Island
Linney Head
Stackpole Quay
1500
0 1 2 3 4
miles

Fig. 15 Map showing the distribution of facies in the basal Viséan rocks in Pembrokeshire.

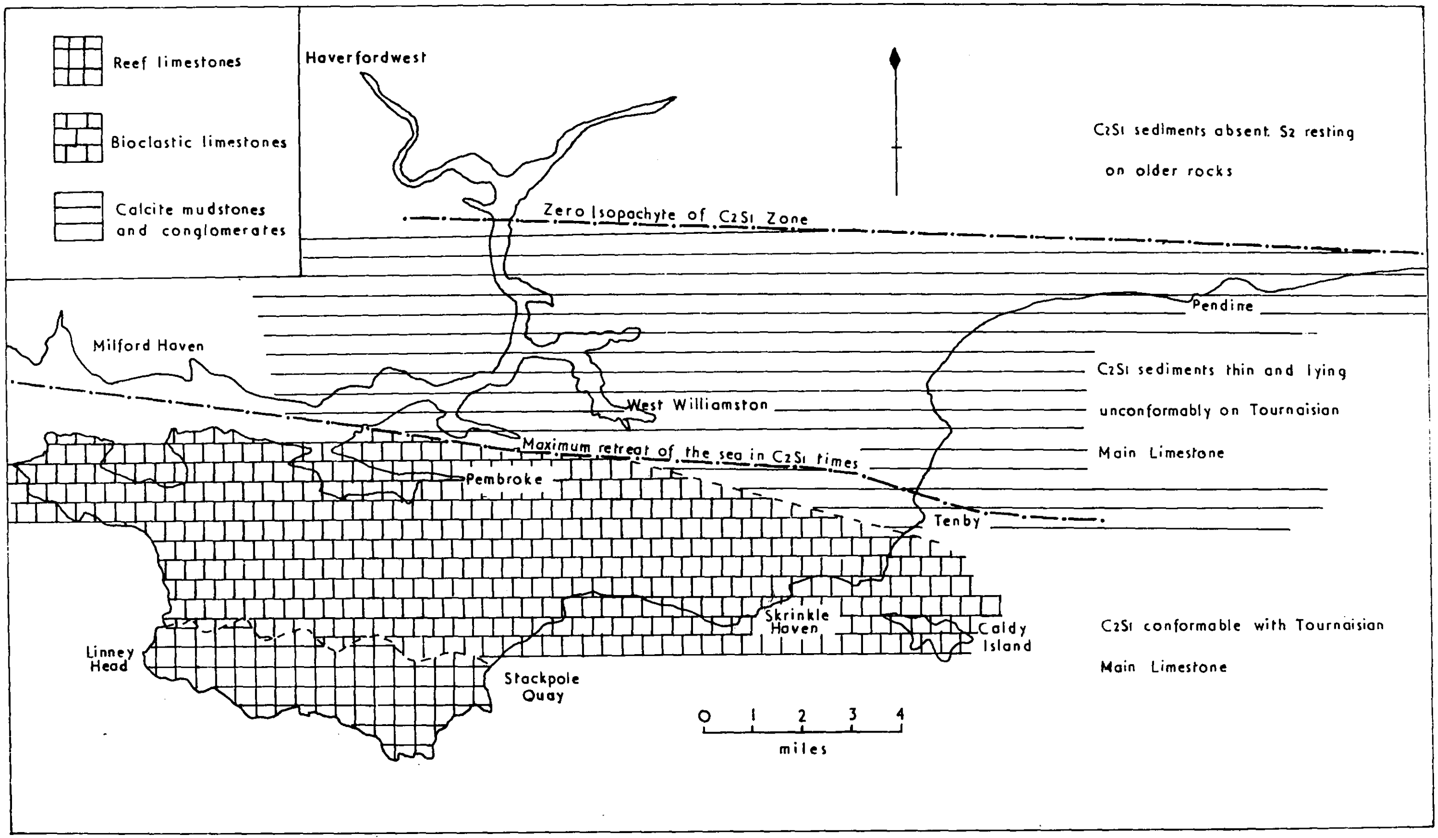
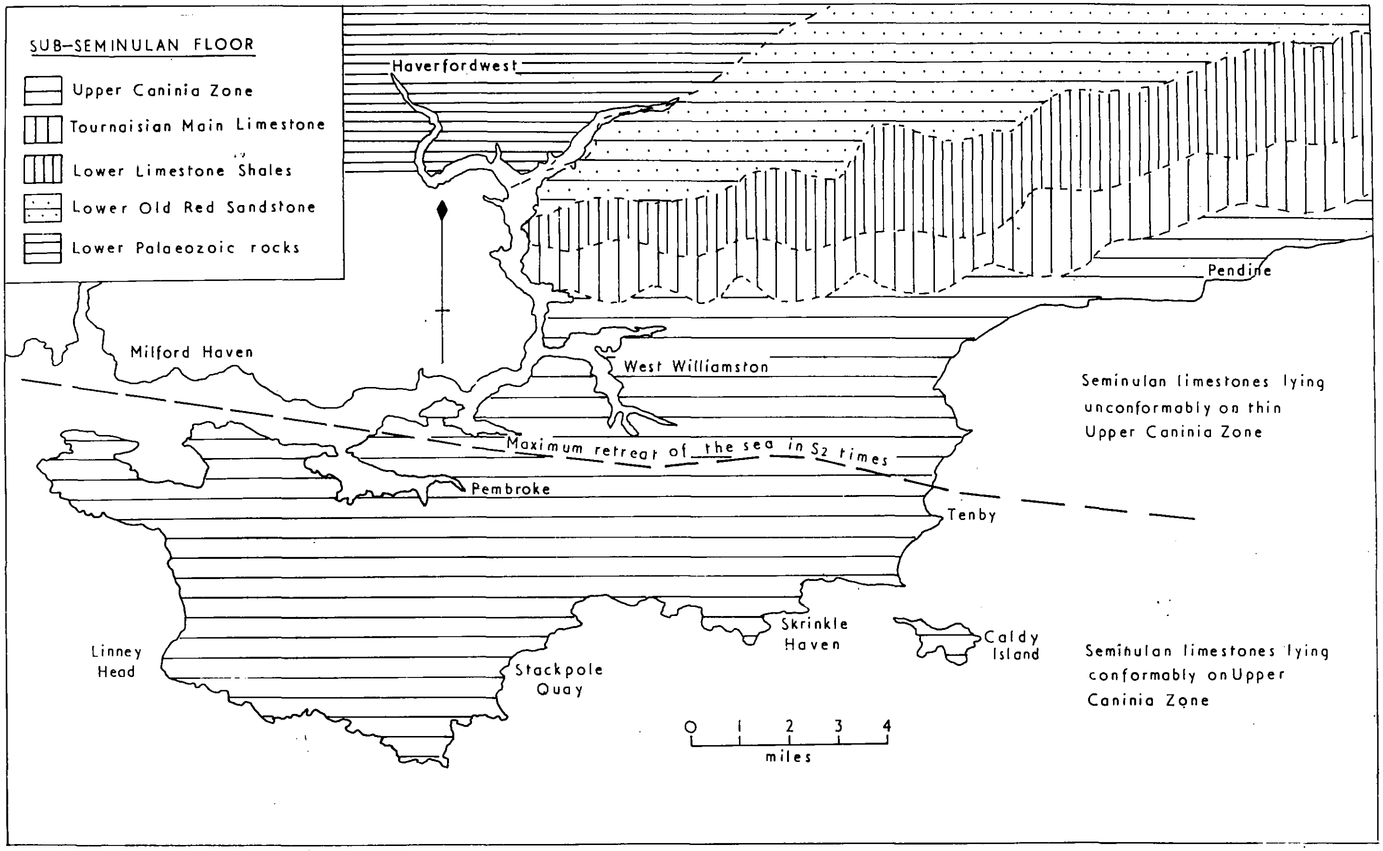

Reef limestones
Bioclastic limestones
Calcite mudstones and conglomerates
Haverfordwest
C2S1 sediments absent. S2 resting on older rocks
Zero Isopachyte of C2S1 Zone
Pendine
Milford Haven
C2S1 sediments thin and lying unconformably on Tournaisian Main Limestone
West Williamston
Maximum retreat of the sea in C2S1 times
Pembroke
Tenby
Skrinkle Haven
Caldy Island
C2S1 conformable with Tournaisian Main Limestone
Linney Head
Stackpole Quay
0 1 2 3 4
miles

Fig. 16 Map illustrating the sub-Seminulan floor in Pembrokeshire.


SUB-SEMINULAN FLOOR
Upper Caninia Zone
Tournaisian Main Limestone
Lower Limestone Shales
Lower Old Red Sandstone
Lower Palaeozoic rocks
Haverfordwest
Milford Haven
West Williamston
Maximum retreat of the sea in S_2 times
Pembroke
Tenby
Pendine
Linney Head
Stackpole Quay
Skrinkle Haven
Caldy Island
Seminulan limestones lying unconformably on thin Upper Caninia Zone
Seminulan limestones lying conformably on Upper Caninia Zone
0 1 2 3 4
miles

the magnitude of the erosion in the north of Pembrokeshire, uplift need not have been great; a gentle tilt would have been sufficient to have caused a widespread retreat of the sea. An estimated slope of 1 in.80, normal to the depositional strike, was required for the removal of some 400 feet of strata between Pendine and Tenby.

Viséan transgression took place northwards in Pembrokeshire across a bevelled surface of Tournaisian rocks. Only at Pendine and at West Williamston are there littoral deposits at the base of the Viséan, where the Tournaisian surface is irregular. Elsewhere in northern Pembrokeshire the Upper Caninia Zone deposits lie with an even, though usually abrupt, junction on the underlying Tournaisian Main Limestone. The Upper Caninia Zone in the northern outcrops are, nevertheless, composed of shallow water "lagoon phase" deposits providing a lithological pointer to the break.

The "lagoon phase" deposits are 50-60 feet thick at the base of the Upper Caninia Zone in the Tenby outcrop. However, immediately to the south, the contemporary deposits in the northern limb of the Pembroke Syncline (a mile or so across the depositional strike) are richly fossiliferous calcarenites with abundant crinoids, brachiopods and corals which demonstrate the rapid onset southwards of open-sea conditions.

It is probable that the northward transgression of the Viséan was diachronous and therefore it is unlikely that the "lagoon phase" deposits are everywhere of the same age (George 1958 p.254).

The sedimentary environment of these "lagoon phase" deposits has been discussed by Dixon (Dixon and Vaughan 1912, pp 511-541) and George (1954 pp 306-307, 1958 pp 254-251). Essentially the rocks are of probably extremely shallow-water origin, deposited in coastal flats perhaps protected from the open sea since interbedded bioclastic limestones are generally absent.

Knowledge of the palaeogeography of the Upper *Caninia* Zone in the north of Pembrokeshire is greatly reduced by Seminulan overstep. It is certain that the maximum advance of the Upper *Caninia* Zone was to the north of Pendine (see figs.14 and 15) but there is doubt whether the shallow-water coastal flats were flooded by the open-sea waters from the south during later Upper *Caninia* Zone times, and their deposits removed by pre-Seminulan erosion. It is not unlikely that the line of the present Ritec fault continued to be important throughout Upper Caninian times and defined a persistant shallow area to the north.

In contrast, south of the Ritec fault there lay an extensive open sea whose floor had a gentle southerly tilt and whose sediments were uniformly bioclastic. The waters were subject to the quiet action of tides, waves, and currents but there is no evidence of the cross-bedding, scouring, lenticular bedding, and rapid changes in facies associated with a shallow-water environment dominated by strong wave action. The rocks deposited in this neritic environment are massive calcarenites deposited in shallow agitated waters, the grains being winnowed and sorted by currents. The included intraclast fragments in the calcarenites point to the erosion of penecontemporaneous limestones (see Folk 1959 p.4). The sea was inhabited by a rich fauna of corals and brachiopods; foraminifera and algae flourished at times.

These uniform neritic conditions persisted throughout the greater part of Upper Caninian times over the Pembroke and Tenby outcrops. Southwards, the sea floor steepened gradually and under quieter and muddy conditions "zaphrentid phase" sedimentation continued into Lower Viséan from Tournaisian times in the Bosherston outcrop. Only the early reef rocks formed a temporary interruption; they reflect the widespread shallowing resulting from the mid-Dinantian movements. The main reef at the base of the Upper Caninia Zone is considered to be a sheet reef and may possibly have a connection with the Irish reefs at this level.

The small patch reefs grew from a number of root points and the surrounding banks of crinoidal debris resemble the "crinoid gardens" described from many reefs (e.g. by Harbough (1957) from the Mississippian of Oklahoma). The reef debris at the crest of the patch reefs indicates that the reef was near-surface and was eroded in shallow water. The reefs present the usual sharp contrast to the enclosing "zaphrentid phase" sediments and reflect the contrasted depositional environments of the mounds and the muddy flats in which the surrounding sediments were deposited. If the sheet reef formed an extensive barrier in early Viséan times, the calcarenites of the Pembroke outcrop may be looked upon as rocks of the back-reef zone.

Light bioclastic calcarenites are established at the base of the Seminula Zone in the succession in the Bosherston outcrop. They were deposited under neritic conditions similar to those existing in Upper Caninian times in the Pembroke and Tenby outcrop. This implies that the neritic zone of sedimentation migrated southwards with the onset of the pre-Seminulan movements.

The neritic Seminulan of the Bosherston outcrop was flanked on the landward side by wide shallow-water areas in which were deposited extensive oolites. The northern boundary of the sea was along the line of the Ritec fault at the onset of the intra-Viséan movements (see fig.16). The rocks to the north were uplifted and eroded and when the movements were followed by marine transgression, the Seminulan seas spread northwards across the bevelled surface of older rocks. At intervals the southern limit of oolite deposition migrated southwards across the belt of crinoidal limestones. The migration was pulsatory, as shown by the interbedding of oolites and crinoidal limestones in the _Seminula_ Zone of the Bosherston outcrop (see fig.10).

V. DISTRIBUTION AND VARIATION OF THE FAUNA IN THE MID-DINANTIAN ROCKS OF PEMBROKESHIRE

Dixon (1921 pp.73-82) compiled an excellent faunal list, which is revised and enlarged upon in the present account, giving the vertical ranges of the fossils in the Dinantian in Pembrokeshire. To supplement the faunal lists it is proposed briefly to describe the distribution and lateral variation in the fauna in the mid-Dinantian rocks of the area.

1. The Bosherston Outcrop

There was in south Pembrokeshire a free migration of a rich fauna unparalleled elsewhere in the S.W. Province. Conditions were broadly uniform throughout the Tournaisian Main Limestone and the greater part of the Upper *Caninia* Zone. The resulting "zaphrentid-phase" sediments contain a highly varied coral-brachiopod-bryozoan fauna and, in addition, trilobites, lamellibranchs, gasteropods and echinoderms are locally abundant.

The various stocks become represented at the base of the Tournaisian Main Limestone and continue upwards with only minor variations to the top of the Upper

Caninia Zone. New forms successively supplement the fauna, their appearance contemporaneous over wide areas.

In the lowest part of the Tournaisian Main Limestone small chonetids, occasional zaphrentoids and small transverse forms of the *Spirifer tornacensis* group are the most abundant forms present. With the incoming of *Caninophyllum patulum* marking the local base of the Lower *Caninia* Zone, as defined by Dixon, an abundant fauna appears. *Caninia cornucopiae* occurs in large numbers, together with species of *Rotiphyllum*, *Allotropiophyllum*, *Cryptophyllum*, *Amplexus*, *Cyathaxonia*, *Zaphrentites*, *Cravenia* and early Koninckophyllids. The *Spirifer tornacensis* group continues upwards and higher in the Tournaisian succession and is accompanied by a large, more elaborate, and less transverse form, *Spirifer* cf. *konincki*. The loosely septate variety of *Caninophyllum patulum* is also a typical high Tournaisian form. In addition, syringothyrids, tylothyrids, rhynchonellids, spiriferinellids, rhipidomellids, schizophoriids, orthotetids and frilled athyrids are abundant and characteristic throughout "zaphrentid phase" sedimentation. The most common orthetetid is *Schellwienella aspis* and at higher horizons it is accompanied by *Schellwienella aspis* mut *radialiformis* (page 140) and *Schuchertella* cf. *fascifera* (page 141) small dictyoclostids, including *Dictyoclostus vaughani* and *Dictyoclostus* cf. *teres* are also common together with pustulids.

The fauna in the massive reef at the base of the Upper *Caninia* Zone has been obliterated by dolomitization except for occasional bryozoa, crinoids and a single specimen of *Syringopora*. In the beds immediately above the reef, however, there appear many new forms. *Lithostrotion* enters the succession, *Caninophyllum patulum* is replaced by corals of the *Caninia cylindrica-benburbensis* group as the dominant caninioid coral. In addition, *Caninia caninoides*, a form characteristic of this Zone in the Mendips, is present, together with *Amplexizaphrentis* aff *enniskilleni* and species of *Koninckophyllum* (*K. praecursor* and *K. cyathophylloides*). The small solitary corals and tabulate corals of the Tournaisian continue upwards /

with little change.

The host of typical "zaphrentid phase" brachiopods established in the Tournaisian continue upwards. Spirifer cf. konincki replaces Spirifer tornacensis as the most important spiriferid, although occasional transverse forms, referable to the latter group occur in the lower part of the Upper Caninia Zone. Schuchertella cf. fascifera becomes the most abundant orthetetid. An important addition to the fauna in the lower part of the Zone is Daviesiella destinezi.

The upper part of the Upper Caninia Zone in the Bosherston outcrop is characterized by abundant Lithostrotion which comes in abundantly in the middle of Group 8 (Dixon, 1921, p.130) and often well-preserved colonies are weathered out in the mudstone. New additions to the coral fauna in the upper parts of the Zone include a new species of compound Koninckophyllum (see page 119) and Caninophyllum archiaci. Numerous large dictyoclostids are also to be found together with linoproductids and many kinds of pustulids, including species of *Echinoconchus*, *Pustula*, *Plicatifera* and *Krotovia*. Additions to the orthetetid stock in the upper part of the Upper *Caninia* Zone are the first known *Orthetetes* (s.l.) from the British Dinantian and large transverse derbyas.

At the top of the Upper *Caninia* Zone in the Bosherston outcrop the "zaphrentid phase" limestones are replaced by light-grey calcarenites and oolites assigned to the *Seminula* Zone. The incoming of the new facies introduces a new faunal assemblage. The abundant and diverse fauna is absent. Only occasional corals of the *Caninia cylindrica* group, koninckophyllids, species of *Carcinophyllum* and *Lithostrotion* occur above in the Seminulan limestones. The diagnostic *Davidsonina carbonaria* has been recorded from the base of the Zone by Dixon (1921 p.133). The large *Daviesiella destinezi* gives place to small papilionaceous chonetids. The abundant productids are represented only by linoproductids and rare pustulids. Smooth athyrids complete the Seminulan fauna.

2. Outcrops north of Bosherston

The change in facies northwards is reflected in a marked change in the fauna. The unsorted muddy bioclastic limestones of southern Pembrokeshire are replaced by well-sorted bioclastic limestones and oolites reflecting shallowing of the waters in which they were deposited. With this facies change the solitary corals and abundant brachiopods disappear. The fauna in these deposits in northern outcrops is never so rich and varied.

The facies change, however, does not take place until the upper part of the Tournaisian Main Limestone in the southern limb of the Pembroke Syncline, but northwards the onset of the shallower-water limestones appears lower in the succession. As a result, "zaphrentid phase" deposits persist into the lower part of the Tournaisian Main Limestone and there is a faunal link between north and south Pembrokeshire in the Tournaisian. This link is particularly well seen in the southern limb of the Pembroke Syncline where numerous forms recorded in the Bosherston /

outcrop continue. Thirty species of brachiopods are common to both areas (see page 145) and once more appear in abundance in the succession, together with numerous solitary corals, with the incoming of Caninophyllum patulum. In addition, new forms appear which are not found to the south and include Avonia bassa, Camarotechia mitcheldeanensis and Buxtonia scrabicula which are common in the Tournaisian in the northern outcrops.

With the incoming of interbedded oolites and bioclastic limestones in the upper part of the Tournaisian Main Limestone, the rich and varied coral-brachiopod fauna disappears. Tabulate corals (Syringopora and Michelinia), species of Chonetes (C. hardrensis and papilionaceous chonetids) and orthetetids (Schellwienella crenistria and Schuchertella wexfordensis) are the dominant forms in the upper part of the Tournaisian Main Limestone.

The link between the Bosherston outcrop and the areas to the north is not so well established in the lower part of the Viséan. The rich "zaphrentid phase" /

limestones die out south of the Pembroke Syncline. The Upper *Caninia* Zone of the Pembroke and Tenby Synclines is mainly represented by well-sorted bioclastic limestones. The fauna consists mainly of smooth athyrids, orthetetids, species of *Chonetes*, *Syringothyris*, *Linoproductus*, and *Dictyoclostus*. Corals of the *Caninia cylindrica* group continue upwards from the Tournaisian together with *Spirifer* cf. *konincki*. *Daviesiella destinezi* and *Caninia caninoides* form a link with the Upper *Caninia* Zone of the Bosherston outcrop. However, *Palaeosmilia murchisoni*, not recorded to the south, is extremely abundant in this Zone in the Pembroke and Tenby Synclines. Tabulate corals and gasteropods complete the fauna of the Upper *Caninia* Zone.

Across the Ritec fault the Upper *Caninia* Zone is represented only by a thin series of calcite mudstones and conglomerates deposited under extremely shallow conditions on the margins of St. George's Land. This is reflected in the complete absence of open sea corals and brachiopods and the only forms present are algae, ostracods, *Spirorbis* and minute lamellibranchs.

As in the Bosherston outcrop, a marked lithological change takes place at the top of the Upper *Caninia* Zone in north Pembrokeshire. At this point in the succession, dark oolites and thin interbedded algal limestones are established. The faunal change at this junction is similar to that recorded at Bosherston. *Davidsonina carbonaria* enters at the base and typical Seminulan forms include species of *Syringopora*, *Carcinophyllum*, *Lithostrotion*, *Chonetes*, and *Linoproductus*. In addition, occasional specimens of corals of the *Caninia cylindrica* group are found in the lower parts of the Zone.

VI CUMMINGS'S FORAMINIFERAL ZONES

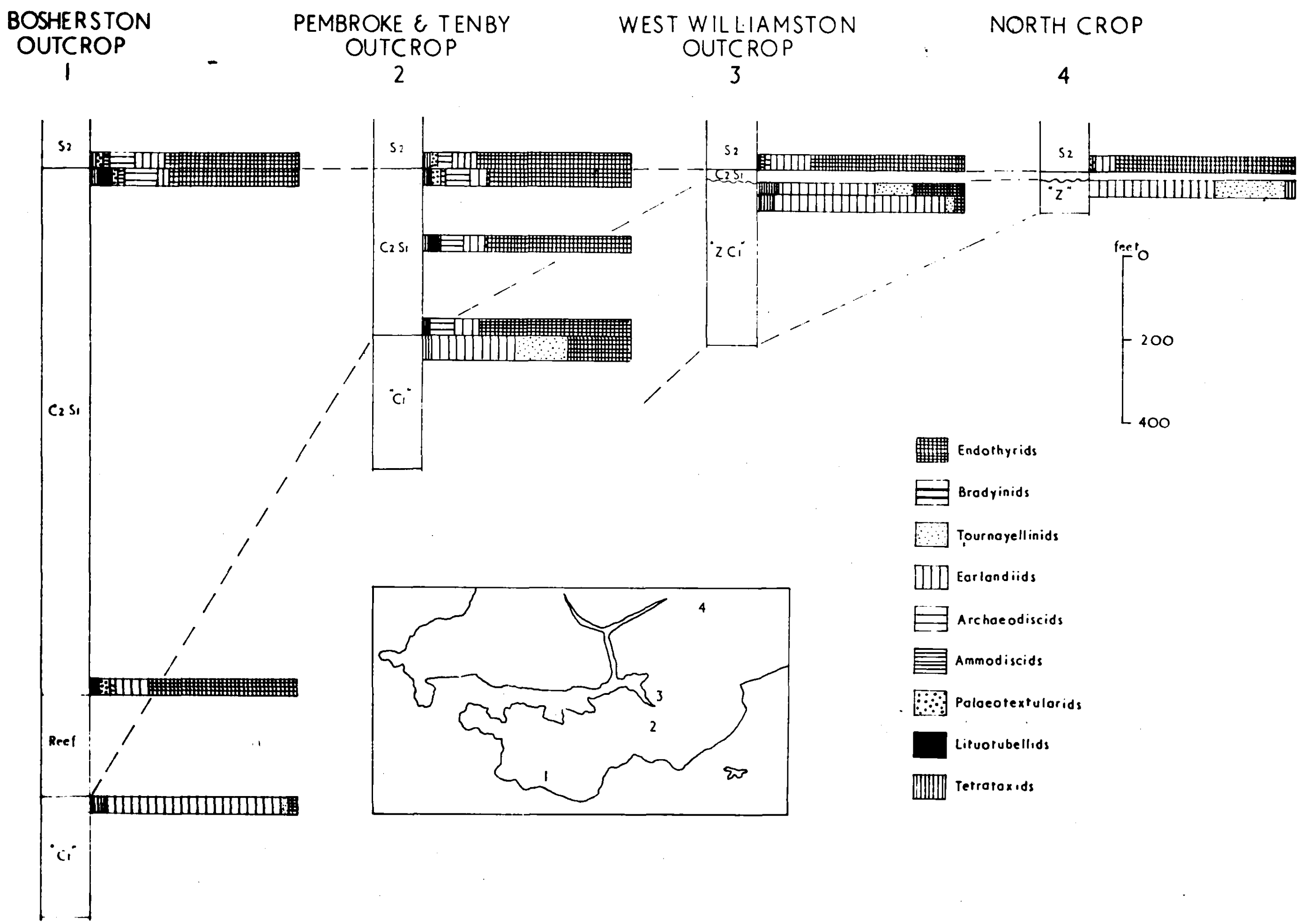
The British Dinantian is being subdivided by Cummings into Foraminiferal Zones based on the sequence of smaller foraminiferal assemblages. This subdivision has been correlated to Vaughan's zonation:

Foraminiferal	Zone	8	_Dibunophyllum_ Zone
"	"	7	
"	"	6	_Seminula_ Zone
"	"	5	
"	"	4	Upper _Caninia_ Zone
"	"	3	
"	"	2	Lower _Caninia_ (C_1) and the upper part of the _Zaphrentis_ (Z_2) Zones
"	"	1	Lower part of the _Zaphrentis_ Zone (Z_1) and the _Cleistopora_ Zone (K)

In the present account only the Foraminiferal Zones 2,3,4 and 5, that is, those covering the mid-Dinantian interval, are considered in any detail,

The division between Foraminiferal Zones 2 and 3 corresponds to the junction between the Tournaisian and Viséan as already defined by the author. The division between 4 and 5 corresponds to the boundary between the Upper _Caninia_ and _Seminula_ Zones. Moreover, these divisions were clearly defined in Pembrokeshire.

Fig. 17 Quantitive distribution charts of the foraminifera in the mid-Dinantian rocks of Pembrokeshire.



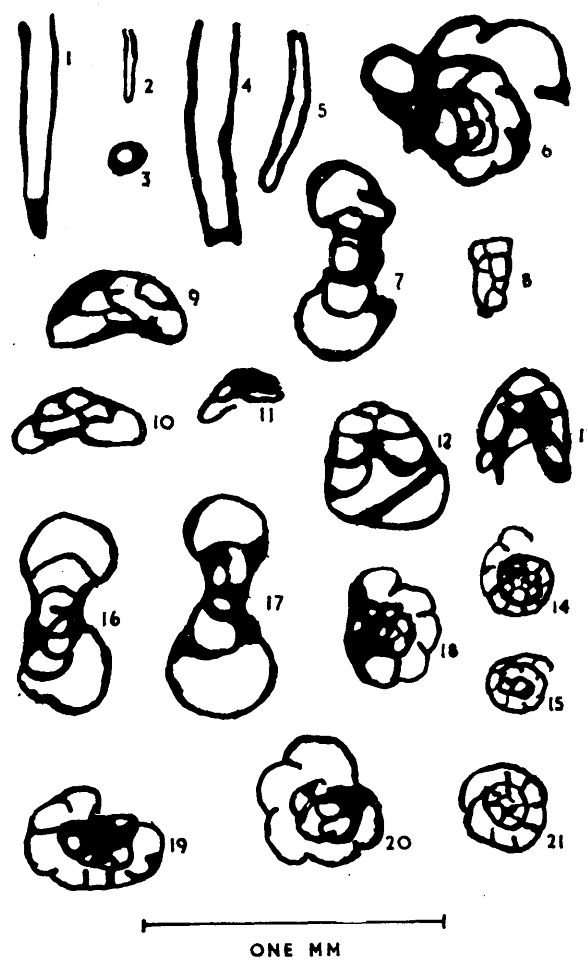
BOSHERSTON OUTCROP
1
PEMBROKE & TENBY OUTCROP
2
WEST WILLIAMSTON OUTCROP
3
NORTH CROP
4
S2
C2 S1
Reef
"C1"
"Z C1"
"Z"
feet
0
200
400
Endothyrids
Bradyinids
Tournayellinids
Earlandiids
Archaeodiscids
Ammodiscids
Palaeotextularids
Lituotubellids
Tetrataxids

EXPLANATION OF PLATE XXIII

Foraminiferal Assemblage. Tournaisian Main Limestone (Foraminiferal Zone 2)

figs.1-3	Earlandiids	Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop
figs.4-5	Earlandiids	Tournaisian Main Limestone, Carew, West Williamston outcrop
figs.6-7	Tournayellinids	Oolite Group, Pendine, North Crop
fig.8	Stacheoides	Upper part Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop.
figs.9-10	Globovalvuline bristolensis (Reichel)	Caninia Oolite, West Williamston
fig.11	Globovalvulina bristolensis (Reichel)	Caninia Oolite, Black Mixen, Pembroke Syncline
figs.12-13	Globovalvulina	Upper part of Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop.
figs.14-15	Plectogyrids	Upper part Tournaisian Main Limestone, Skrinkle Haven, Pembroke Syncline.
figs.16-17	Tournayellinids	Oolite Group, Pendine.
figs.18-19	Tournayellinids	Top Caninia Oolite, Black Mixen, Pembroke Syncline.
fig.20	Tournayellinid	Base of Oolite Group, Pendine.
fig.21	Plectogyrid	Top Caninia Oolite, Black Mixen, Pembroke Syncline.

FORAMINIFERAL ASSEMBLAGE.
TOURNAISIAN MAIN LIMESTONE



However, the division between Foraminiferal Zones 1 and 2 and 3 and 4 are not so distinct, there is no well defined faunal change defining them and, due to inadequate collecting, these divisions could only be placed approximately in the sequences. Nevertheless, by using the assemblages of foraminifera it is possible broadly to subdivide the mid-Dinantian rocks of Pembrokeshire and it can be demonstrated that the Foraminiferal Zones correspond approximately to the groups defined by corals and brachiopods.

Foraminiferal Zone 2 (see plate XXIII)

This Foraminiferal Zone covers the greater part of the Tournaisian Main Limestone. The most common forms include earlandiids, small plectogyrids and tournayellinids. Foraminifera are, however, never abundant in this Foraminiferal Zone and are only sporadically developed.

Earlandiids are generally the commonest group, amounting to between 35-40% of the total foraminiferal fauna. Plectogyrids make up approximately 30% and tournayellinids 20%. Locally one group may predominate over all others, as in the Bosherston outcrop where the earlandiids are extremely abundant and the plectogyrids and tournayellinids rare. This concentration of earlandiids in the upper part of the Tournaisian Main Limestone is again seen in the bioclastic limestones underlying the Caninia Oolite in the West Williamston outcrop.

In the upper part of Foraminiferal Zone 2, early members of the family Tetrataxidae and palaeotextularids appear. The earliest record of the Tetrataxidae is in the rocks 100 feet below the Caninia Oolite at West Williamston where Globivalvulina is recorded. Moreover, the genus is commonly represented by G.bristolensis in the Caninia Oolite of West Williamston and in the Pembroke Syncline. It also occurs in the beds below the reef limestones in the Bosherston outcrop.

The palaeotextularids are represented by occasional forms referable to the genus Palaeotextularia. They are recorded in the upper part of the Tournaisian succession in the Bosherston outcrop and occur rarely in the Caninia Oolite in the outcrops to the north.

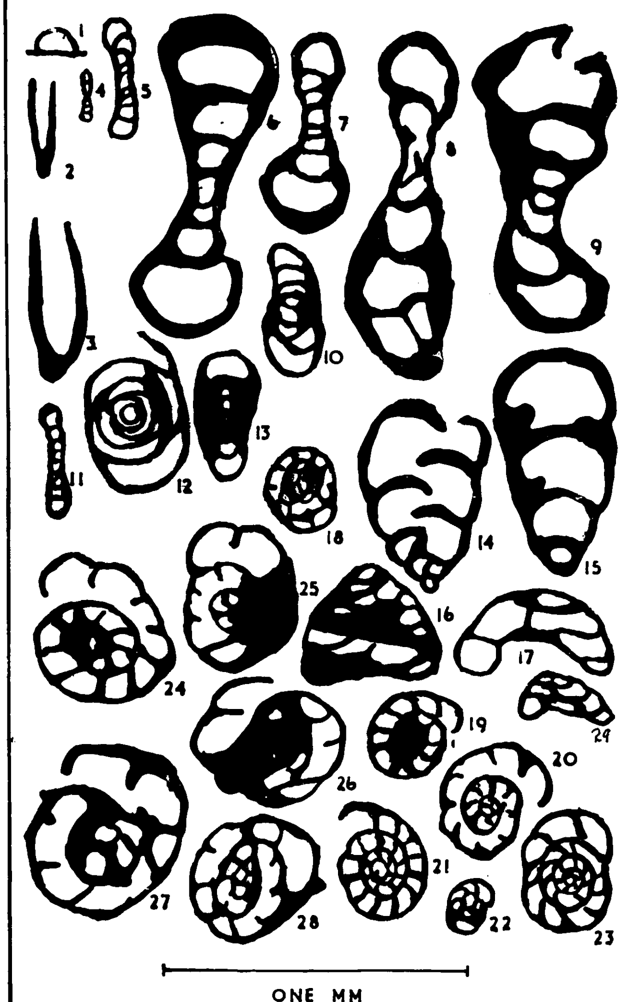
EXPLANATION OF PLATE XXIV

Foraminiferal Assemblage. Lower part of Upper Caninia Zone (Foraminiferal Zone 3)

fig.1	*Tuberitina*	Black Mixen, Pembroke Syncline
figs.2-3	Earlandiids	" " " "
figs.4-5	Ammodiscids	" " " "
fig.6	Lituotubellid	Stackpole Quay, Bosherston outcrop
figs.7-9	Lituotubellids	Black Mixen, Pembroke Syncline
fig.10	Archaeodiscid	Black Mixen, Pembroke Syncline
fig.11	*Para-archaeodiscus*	Black Mixen, Pembroke Syncline
fig.12	Archaeodiscid	Black Mixen, Pembroke Syncline
fig.13	*Permodiscus*	Black Mixen, Pembroke Syncline
figs.14-15	Palaeotextularid	Linney Head, Bosherston outcrop
fig.16	Tetrataxid	Linney Head, Bosherston outcrop
fig.17	*Globovalvulina*	Linney Head, Bosherston outcrop
figs.18-19	Endothyrids	Black Mixen, Pembroke Syncline
fig.20	*Endothyra*	Linney Head, Bosherston outcrop
fig.21	*Endothyra*	Black Mixen, Pembroke Syncline
fig.22	Small plectogyrid	Linney Head, Bosherston outcrop
fig.23	*Endothyra*	Black Mixen, Pembroke Syncline
fig.24	Endothyrid	Linney Head, Bosherston outcrop
fig.25-26	Plectogyrid	Linney Head, Bosherston outcrop
fig.27	Early *Endothyranopsis*	Black Mixen, Pembroke Syncline
fig.28	Plectogyrid	Black Mixen, Pembroke Syncline
fig.29	*Globovalvulina*	Black Mixen, Pembroke Syncline

FORAMINIFERAL ASSEMBLAGE.

LOWER C_2S_1



A typical upper Tournaisian Main Limestone assemblage would include the following genera: *Globivalvulina*, *Tournayellina*, *Glomospira*, *Plectogyra*, *Palaeotextularia* and *Earlandia* (see plate XXIII)

Foraminiferal Zones 3 and 4 (see plates XXIV, XXV)

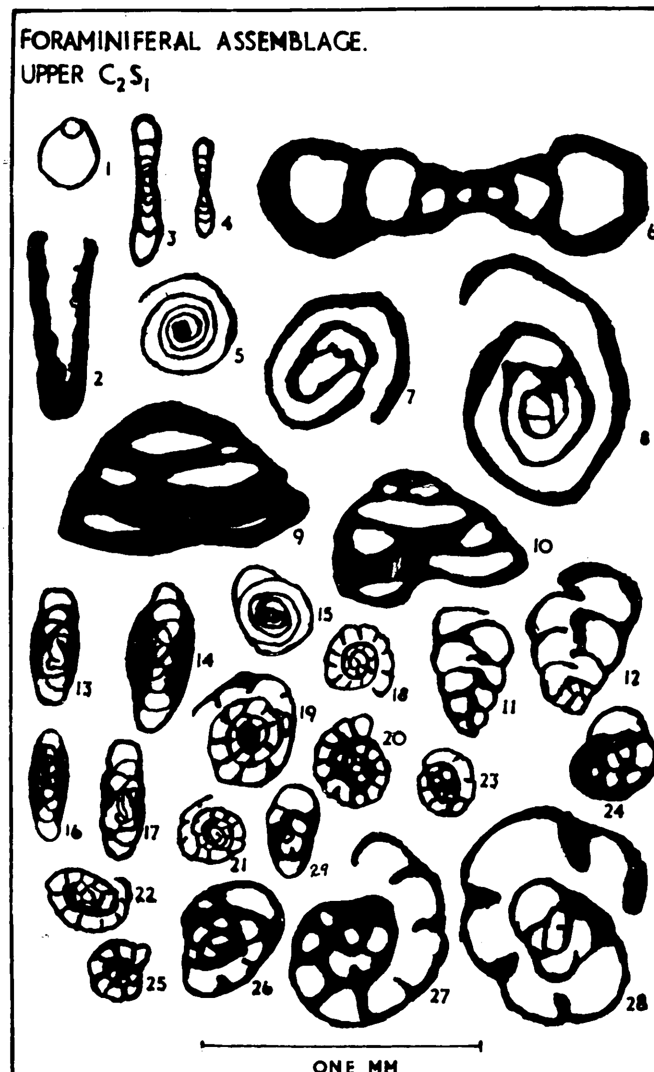
At the top of the *Caninia* Oolite or its equivalent horizon in Pembrokeshire there is an abrupt faunal change in the foraminiferal assemblages. It corresponds to the faunal change already discussed in the corals and brachiopods and substantiates the author's interpretation in drawing the Tournaisian and Viséan boundary at this horizon.

The Foraminiferal Zones 3 and 4 may be equated to the Upper *Caninia* Zone; the division between the two Foraminiferal Zones is not clearly defined. In the lowest part of the Upper *Caninia* Zone the first *Endothyra*, bradyinids and archaeodiscids appear in the succession. They occur in the beds overlying the dolomitized reef limestones at Blucks Pool and Stackpole Quay, in the bioclastic limestones overlying the *Caninia* Oolite in the Pembroke Syncline, and in the "lagoon phase"

EXPLANATION OF PLATE XXV

Foraminiferal Assemblage. Upper part of Upper Caninia Zone (Foraminiferal Zone 4)

fig.1	*Tuberitina*	The Wash, Bosherston outcrop
fig.2	Earlandiids	The Wash, Bosherston outcrop
figs.3 & 5	Ammodiscids	The Wash, Bosherston outcrop
fig.4	Ammodiscid	South Sands, Tenby
figs.6 & 8	Lituotubellid	The Wash, Bosherston outcrop
fig.7	Lituotubellid	South Sands, Tenby
figs.9 & 10	Tetrataxids	The Wash, Bosherston outcrop
figs.11 & 12	Palaeotextularids	The Wash, Bosherston outcrop
figs.13 & 15	Archaeodiscids	Black Mixen, Pembroke Syncline
fig.16	*Propermodiscus*	The Wash, Bosherston outcrop
fig.17	Archaeodiscid	The Wash, Bosherston outcrop
figs.18 & 20-21	*Endothyra*	The Wash, Bosherston outcrop
fig.19	Endothyrid	South Sands, Tenby
fig.22	Endothyrid	The Wash, Bosherston outcrop
figs.23-26	Plectogyrids	The Wash, Bosherston outcrop
figs.27-28	*Endothyranopsis*	The Wash, Bosherston outcrop
fig.29	Plectogyrid	The Wash, Bosherston outcrop.


FORAMINIFERAL ASSEMBLAGE.
UPPER C_2S_1
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ONE MM

in the Tenby outcrop.

The endothyrids make up approximately 75% of the Upper *Caninia* Zone foraminiferal fauna (see fig 17). The group is mainly represented by plectogyrids, which continue up from the Tournaisian and by *Endothyra*.

The family Bradyinidae are represented by early forms of *Endothyranopsis*. They make their first appearance in the upper part of Foraminiferal Zone 3 (for example, in the upper part of Dixon's group 2, 1921, p.101, in the Pembroke Syncline) and they increase in number upwards in the Upper *Caninia* Zone. However they are never abundant and never exceed 5-10% of the total foraminiferal assemblage. Their presence indicates a high horizon in the Upper *Caninia* Zone and Foraminiferal Zone 4.

The archaeodiscids are an important group though locally they may be less abundant. They are rare, for example, in the lower part of the Upper *Caninia* Zone directly overlying the reef limestones at Linney Head but elsewhere in Pembrokeshire they are abundant throughout the Zone. The early archaeodiscids in the lower part of the Visean are represented by such regularly-coiled forms as _Permodiscus_ and _Para-archaeodiscus_ but _Archaeodiscus_ later becomes the dominant member of the family. The abundance of the irregularly coiled _Archaeodiscus_ in the rocks would suggest Foraminiferal Zone 4.

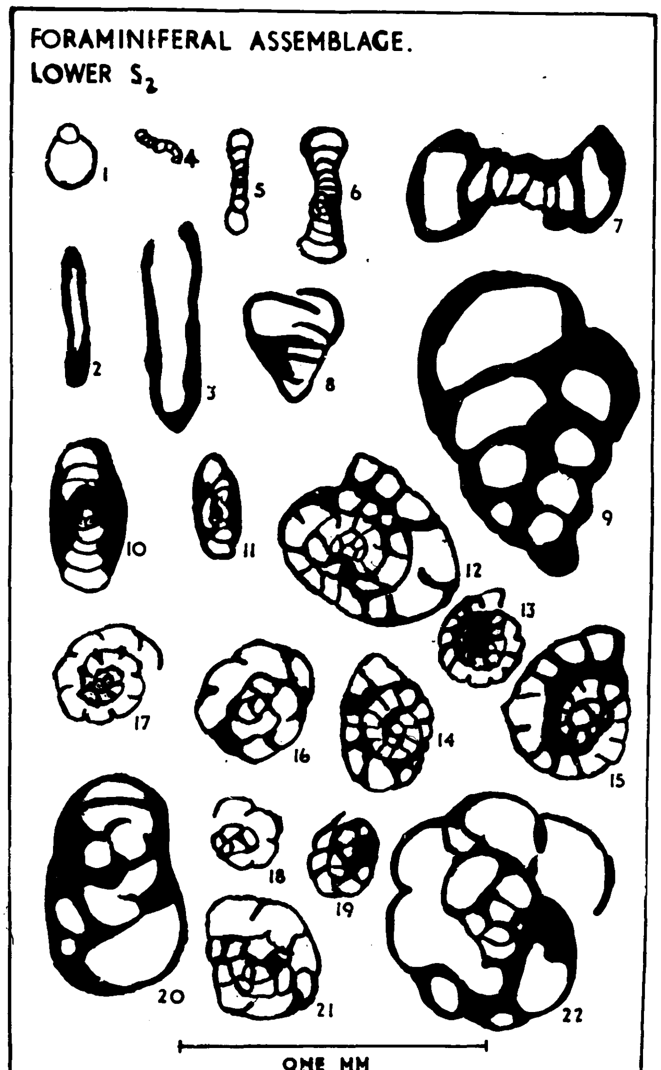
Members of the family Tetrataxidae and palaeotextularids persist into the Viséan from the Tournaisian and make up a small percentage of the total fauna. _Tetrataxis_ replaces _Globivalvulina_ as the most common tetrataxid, though the latter genus is still represented in the Upper _Caninia_ Zone. The palaeotextularids include elongate forms, assigned to the genus _Palaeotextularia_, in the lower part of the Upper _Caninia_ Zone (Foraminiferal Zone 3) but "squat" forms become important upwards and are referred to the genus _Cribrostomum_. The appearance of _Cribrostomum_ would suggest that the beds fall within Foraminiferal Zone 4.

Earlandiids continue as an important element in the fauna. Another characteristic group in the Upper

EXPLANATION OF PLATE XXVI

Foraminiferal Assemblage. Lower part of Seminula Zone. (Foraminiferal Zone 5)

fig.1 *Tuberitina*	West Williamston
figs.2-3 Earlandiids	" "
fig.4 Ammodiscid	Near Lydstep, Pembroke Syncline
figs.5-6 Ammodiscids	Radford, West Williamston outcrop
fig.7 Lituotubellid	West Williamston
figs.8-9 Palaeotextularid	Near Lydstep, Pembroke Syncline
figs.10-11 Archaeodiscids	Near Lydstep, Pembroke Syncline
figs.13-15 *Endothyra*	Pendine, North Crop
fig.16 Plectogyrid	" " "
fig.17 Plectogyrid with hooks	Radford, West Williamston outcrop
fig.18-19 Plectogyrid	Bangeston, West Williamston outcrop
fig.20 Plectogyrid	Pendine, North Crop
fig.21 Plectogyrid	Near Lydstep, Pembroke Syncline
fig.22 *Samarina*	Pendine, North Crop


FORAMINIFERAL ASSEMBLAGE.
LOWER S_2
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ONE MM

Caninia Zone comprises occasional lituotubellids, represented by *Lipininella*.

Foraminiferal Zone 5 (see plate XXVI)

At the top of the Upper *Caninia* Zone there is a marked faunal change; the rich and varied fauna is replaced by a fauna consisting dominantly of endothyrids which make up approximately 80% of the total foraminiferal assemblage. The remainder are mainly earlandiids and occasional archaeodiscids, tetrataxids, and lituotubellids. Moreover, there are very few palaeotextulariids in Foraminiferal Zone 5.

The endothyrids consist predominantly of a small *Endothyra* or of such forms such as *Parastafella*. Plectogyrids continue to be an important group and occasionally *Endothyranopsis* and *Samarina* are also found.

VII THE CASTLE HILL FAULT BLOCK

(1) Succession

Castle Hill, to the north of the Tenby Anticline, is a fault block lying between the Ritec fault and a branch that passes to the south (see fig. 18). The fault block has been described by Dixon (1921 pp.88,91-92) and its rocks referred to the Tournaisian Main Limestone.

The succession seen near the Lifeboat Slip is:

3.	Massive, highly dolomitized crinoidal limestones with a thick oolite at the base, the sequence is faulted and it is not possible to determine the thickness, but it is at least 100 feet.	
2.	Dark thinly bedded cherty bioclastic limestones with interbedded shales and mudstones.	110 feet
1.	Massively bedded crinoidal limestones with thin oolites. The base of the group is hidden beneath the sand at Low tide near the Lifeboat House.	50 feet seen.

The upper dolomitic rocks (bed 3) were referred to the <u>Laminosa</u> Dolomite by Dixon. The beds are sheared and mylonized along the southern face of the fault block and extensively veined with calcite. They are dominantly a group of bioclastic limestones with a thick light oolite near the base. Both rock types

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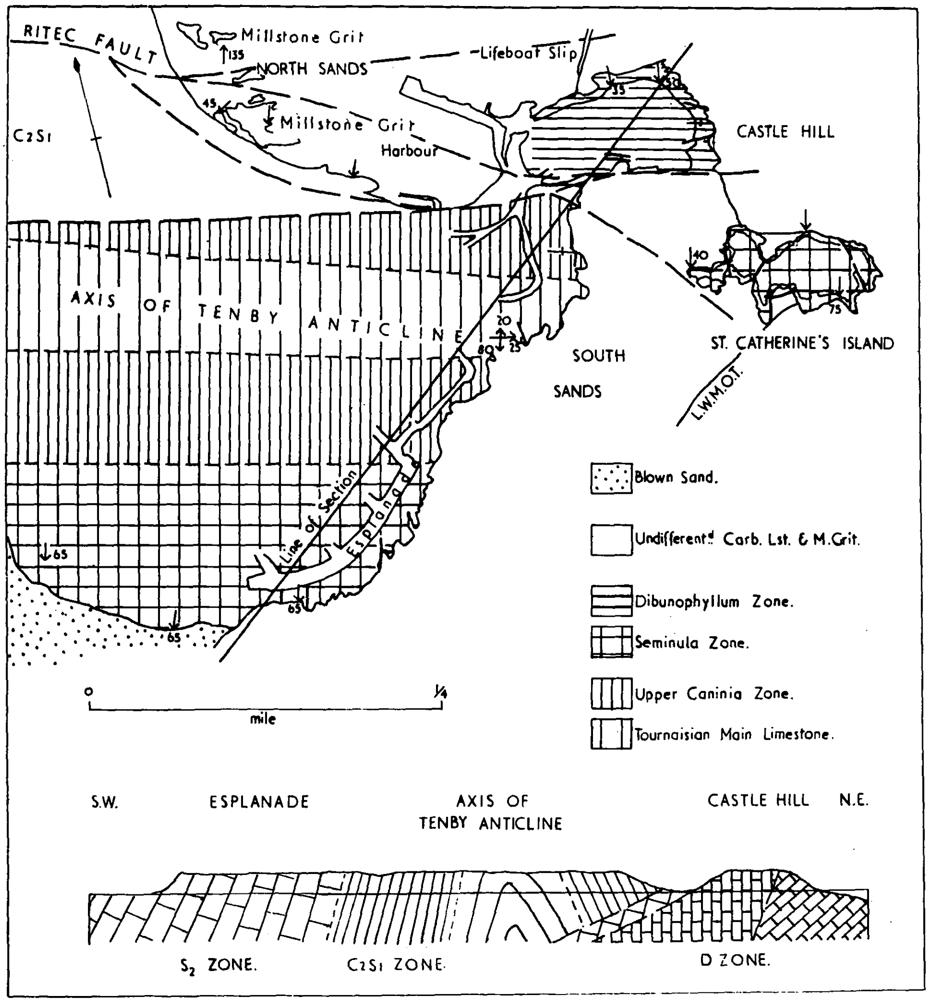
Fig. 18 Map and section showing the Geology of Tenby (amended after Dixon, 1921 fig.6 p.92).



RITEC FAULT
Millstone Grit
135
NORTH SANDS
Lifeboat Slip
45
Millstone Grit
Harbour
C2S1
CASTLE HILL
35
AXIS OF TENBY ANTICLINE
40
75
20
25
80
SOUTH SANDS
ST. CATHERINE'S ISLAND
L.W.M.O.T.
Line of Section
Esplanade
65
65
65
Blown Sand.
Undifferent.d Carb. Lst. & M.Grit.
Dibunophyllum Zone.
Seminula Zone.
Upper Caninia Zone.
Tournaisian Main Limestone.
0
1/4
mile
S.W.
ESPLANADE
AXIS OF TENBY ANTICLINE
CASTLE HILL
N.E.
S2 ZONE.
C2S1 ZONE.
D ZONE.

are seen to be highly recrystallized and sheared under the microscope and little of the details of the original fabric can be made out.

In the middle of the sequence are thin-bedded, dark, fine-grained, bioclastic limestones with abundant dark nodular chert and thin shales and mudstones (Group 3). The development is similar to the "zaphrentid phase" limestones to the south, and they were referred to the Zaphrentis Zone or Horizon γ by Dixon. In thin section the limestones are seen to be fine-grained calcarenites identical with the "zaphrentid phase" limestones previously described from the Bosherston outcrop. They are rich in shell fragments set in a dark argillaceous matrix; and in turn bryozoa and foraminifera are particularly abundant.

Underlying the "zaphrentid phase" limestones are lighter, more massive, bioclastic limestones with thin oolites (Group 1). They were referred to either the Zaphrentis Zone or the Caninia Oolite by Dixon. Microscopically the limestones are well-sorted /

calcarenites. The shell fragments include crinoid remains and abraded brachiopod shells set in a clear recrystallized matrix. Bryozoa and foraminifera are once more abundant. The interbedded oolites are extremely rich in organic fragments and on the whole are well-sorted and highly recrystallized.

(2) The age of the Castle Hill sequence

The association of "zaphrentid phase" limestones with light massive bioclastic limestones and oolites above and below is unlike any Tournaisian rocks seen in Pembrokeshire.

The "zaphrentid phase" limestones yield a fairly abundant fauna including:

Caninia cornucopiae — *Linoproductus* sp.
Zaphrentoids — *Syringothyris* sp.
Eomarginifera cf. *tissingtonensis*
Dictyoclostus sp. — *Rugosochonetes hardrensis*
Orthetetids

E. cf. *tissingtonensis* is a characteristic Viséan form in the Midlands and North of England. Moreover, the foraminifera indicate a *Dibunophyllum* Zone age for the beds. They are common and include *Archaeodiscus*, ammodiscids, Brunsia, Tetrataxis cornu, Globivalvulina, Bradyina, and Fourstonella.

The typical Dibunophyllum Zone of the Tenby outcrop seen in the Black Rock Quarry, a mile or so southwest of Castle Hill, consists chiefly of thick bedded bioclastic limestones and oolites interbedded with pseudobreccias. In the quarry it is exposed to about 150 feet and is underlain by Seminulan limestones. Groups 1 and 3 on Castle Hill are of precisely the same lithology and are almost certainly referable to this Zone. There is, however, no "zaphrentid phase" limestones in the lower part of the Dibunophyllum Zone exposed in Black Rock Quarry and the greater part of the Castle Hill sequence is probably younger than the Black Rock Quarry beds.

"Zaphrentid phase" limestones are developed in the Bosherston outcrop in the Middle Dibunophyllum (D_2) subzone (Dixon 1921 p.135) and contain a fauna similar to the Castle Hill facies. Although Lonsdaleia floriformis (Martin) has not been found on Castle Hill, the Castle Hill beds are thus referable to this subzone.

(3) The Structure of the Castle Hill Fault Block

The revised stratigraphical interpretation of the fault block greatly simplifies the structure which is a faulted inverted limb of an overfold (see fig. 18). The direction of the pressure is from the south, the thrust planes limiting the southern end of the block are inclined at about 30° to the south. The beds in the northern limb of the Tenby Anticline, though less inclined that those in the southern limb, become vertical near the thrusts. Similarly the beds on the northern side of the thrusts, on Castle Hill, dip southwards between 35-50° and in turn become vertical near the thrusts.

VIII PALAEONTOLOGY

1. Caninioid corals in Pembrokeshire

The caninioid corals are referred to the following genera and species:

Caninia cornucopiae (Michelin) emend. Carruthers
Caninia cylindrica (Scouler) - *benburbensis* (Lewis) Group
Caninia caninoides (Sibly)
Caninophyllum patulum (Michelin) emend. Salee
Caninophyllum archiaci (Edward & Haime)

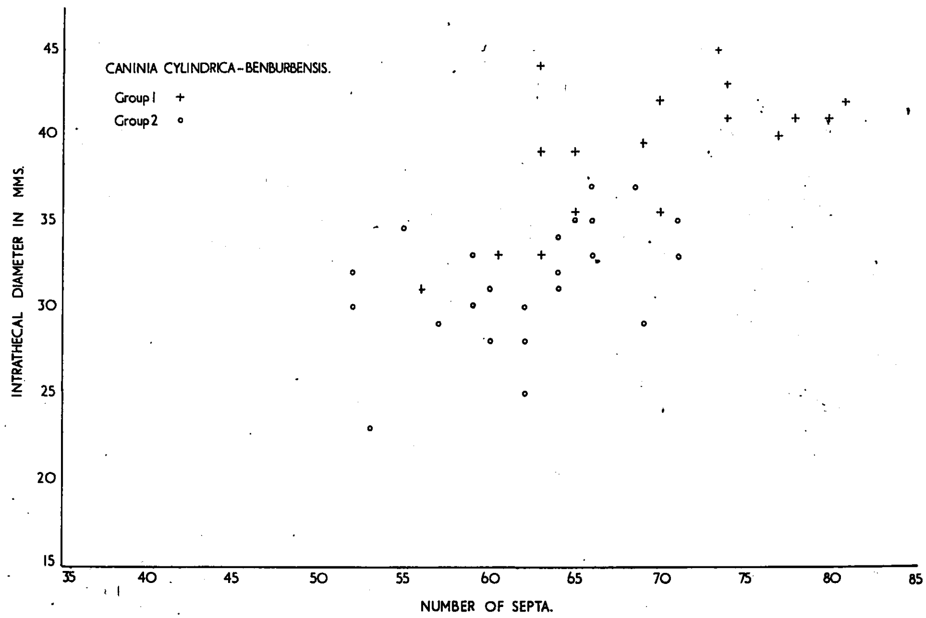
C.cornucopiae (see Carruthers 1908 pp.158-171 pl.VI figs.1-4) *C.caninoides* (Sibly 1906 p.368 pl.XXI figs.2a and 2b) *C.patulum* (Smyth 1930 p.551 pl.XVI fig.1) and *C.archiaci* (Lewis 1929 p.458 pl.XII figs.4a and 4b) recorded in Pembrokeshire are closely comparable to the forms described in the literature and are not now discussed.

(i) Caninia cylindrica - benburbensis group

Lewis (1927 pp.373-381) described and differentiated *C.cylindrica* (Scouler) from *C.benburbensis* (Lewis) on the following criteria :

C.cylindrica	*C.benburbensis*
1. 70-80 septa, diameter 6-7 cms. in mature forms; intrathecal diameter on an average 3.5 cms.	1. 74-60 septa, diameter varying between 7.5-8 cms. in mature forms; intrathecal diameter on an average 3.5 cms.

Fig. 19 Graph showing the relationship of intrathecal diameter and number of septa in the corals of the *Caninia cylindrica-benburbensis* Group from the Upper *Caninia* Zone from the Bosherston outcrop.


CANINIA CYLINDRICA-BENBURBENSIS.
Group I +
Group 2 o
INTRATHECAL DIAMETER IN MMS.
15
20
25
30
35
40
45
35
40
45
50
55
60
65
70
75
80
85
NUMBER OF SEPTA.

<u>C.cylindrica</u>	<u>C.benburbensis</u>
2. Discontinuous major septa in extrathecal area, being represented by septal ridges and absent from the peripheral zone. Continuous in the intrathecal zone.	2. Continuous and straight major septa in the intrathecal zone. Sinuous but continuous in the extrathecal zone.
3. Minor septa project inward for about 2 mm. in the intrathecal zone. Discontinuous in the extrathecal zone.	3. Minor septa do not extend beyond the extrathecal zone. They are discontinuous near the periphery but continuous near the theca.
4. Fossula well marked.	4. Fossula well marked.
5. Dissepiments lonsdaleoid in the extratheca but become concentric in the intrathecal area.	5. Dissepiments of the herring bone and concentric types (see Lewis 1927)
6. Tabulae flat and bent down in longitudinal section, usually complete; average 6 tabulae in 1 cm.	6. Tabulae flat, bent down at the outer edges, but usually complete. 3 or 4 tabulae in 1 cm., 1-4 subsidary tabulae.

There is difficulty in assigning the specimens of large Caninias found abundantly in the Upper <u>Caninia</u> Zone of the Bosherston outcrop to one or other of the two species. They are referable to the <u>C.cylindrica - benburbensis</u> group in being large in size, cylindrical throughout growth, and in having 80-60 major septa which do not reach the centre. The intrathecal diameter varies from 4.8 to 3.6 cms., the ratio of the total diameter: intrathecal diameter : diameter of extrathecal zone is of the order of 1:0.8:0.13. All the forms have discontinuous minor septa, usually extending for a short distance into the intrathecal zone, and numerous dissepiments and tabulae.

They are usually similar to C.benburbensis in the tendency for both major and minor septa to be continuous, particularly near the theca in the extrathecal zone, and in the dissepiments becoming concentric and closely set near the theca. On the other hand, they are similar to C.cylindrica in the development of lonsdaleoid dissepiments in the peripheral past of the extrathecal area and in the minor septa extending for a short distance into the intrathecal zone. Similar transitional forms are described and illustrated by Lewis (1927 p.380 pl.XVI fig.6 and pl.XVII fig.4) and Sibly (1906 pl.XXXI fig.1).

The Pembrokeshire specimens from the Upper Caninia Zone of the Bosherston outcrop show a marked variation in size, number of septa (see fig. 19), dilation of septa, dissepimental and septal arrangements and nature of cardinal fossula. In the study of the ontogeny of an

/

individual, many of these variations are apparent. Size and number of septa increase with growth until the mature stage is reached when the number of septa remains constant and the coral only increases in size. Variation in dilation of septa and nature of cardinal fossula can be shown to vary greatly within one specimen (see pl. XXVII fig. I). Moreover, differences in dissepimental arrangement are present in one individual. Thus at one stage in its ontogeny it will exhibit a "cylindrica" arrangement and in a later stage it will revert to the "cylindrica" development.

These variations are not systematic and do not appear to have phylogenetic significance. However, within this complex variation, two distinct forms exist.

(a) GROUP I (Plate XXVII)

This group is represented by large forms often with strongly dilated septa in the intrathecal zone; it has 80-70 septa for an intrathecal diameter of 3.9 cms. The minor septa are continuous for a short distance into the intrathecal zone and then become discontinuous. The peripheral part of the extrathecal zone has prominent

/

EXPLANATION OF PLATE XXV11

Caninia cylindrica (Scouler) - benburbensis (Lewis) Group

fig. 1 a. Transverse section of large form with major septa continuous in extrathecal zone and with a prominent fossula.

b. Transverse section of earlier stage of same specimen showing more dilated major septa and a greater development of lonsdaleoid dissepiments in extrathecal zone. (All x 1)

Lower part of the Upper Caninia Zone, Linney Head, Bosherston Outcrop.

fig. 2 a. Transverse section of large specimen showing minor septa extending for a short distance into the intrathecal zone.

b. Longitudinal section of same specimen showing the well-spaced tabulae (All x 1)

Lower part of the Upper Caninia Zone, Linney Head, Bosherston outcrop.

1a.

b.

2a.

b.

lonsdaleoid dissepiments which are replaced on the inner side by concentric closely set dissepiments.

(b) GROUP II (Plate XXVIII)

This group includes smaller forms with an intrathecal diameter much less than Group I - 3.2 cms. as compared to 3.9 cms. (see fig. 19). The septa are relatively undilated and closely set and 66-63 major septa at 3.2 cms. is typical of the group. The lonsdaleoid peripheral zone is not so prominent. The extrathecal zone is much narrower with numerous concentric dissepiments and discontinuous major and minor septa. The form illustrated by Sibly (1906 pl.XXXI, fig.1) from the "*Syringothyris*" Zone of Vallis Vale belongs to this group.

Remarks

The *C.cylindrica-benburbensis* groups described above are from the Upper *Caninia* Zone of the Bosherston outcrop and they are occasionally found in the lower part of the overlying *Seminula* Zone.

C.cylindrica is recorded from the middle of the Tournaisian Main Limestone of the Pembroke Syncline,

/

EXPLANATION OF PLATE XXV111

Caninia cylindrica (Scouler) - benburbensis (Lewis) Group.

fig. 1 a. Transverse section showing long major septa, minor septa extending into intrathecal zone, prominent lonsdaleoid dissepiments in extrathecal zone, and prominent fossula.

b. Transverse section of earlier stage of same specimen (All x 1)

Lower part of the Upper Caninia Zone, Linney Head, Bosherston Outcrop.

fig. 2 a. Transverse section of small specimen showing long major septa extending almost to the epitheca, minor septa continuous in the extrathecal zone and wide fossula.

b. Transverse section of an earlier stage of same specimen with minor septa extending into the intrathecal zone and only a narrow development of extrathecal zone. (All x 1)

Lower part of the Upper Caninia Zone, Linney Head, Bosherston outcrop.

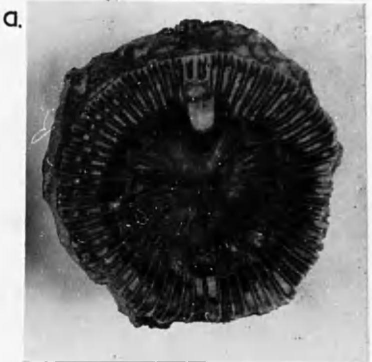
fig. 3 a. Transverse section near calyx.

b. Transverse section at earlier stage of same specimen showing long major septa and dilated fossula.

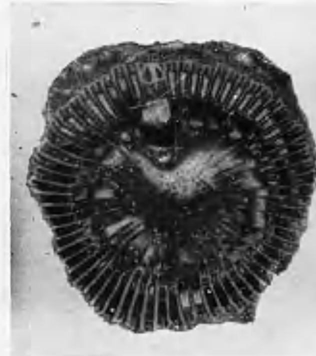
c. Longitudinal section of same specimen (All x 1)

Lower part of the Upper Caninia Zone, Linney Head, Bosherston outcrop.

1a.



b.



2a.

b.

3a.

b.

c.

the Mendips (Vaughan 1905 pl.XXIII fig.1, Reynolds and Vaughan 1911 p.376 pl.XXXI fig.1) and in the Gower (Dixon and Vaughan 1912 p.545). It is in the Tournaisian a clearly defined group showing the lonsdaleoid dissepiments characteristic of Scouler's species. However, in the lower part of the Viséan in both Pembrokeshire and the Mendips, the group acquires a more conspicuous fossula, the septa become extended from theca to the epitheca and concentric dissepiments replace the lonsdaleoid arrangement. This gives rise to the transitional forms discussed above.

The typical C.benburbensis is an upper Viséan form of Ireland and Northern England and shows a further stage in the development of continuous septal arrangement in the extratheca. This trend - the loss of lonsdaleoid dissepiments and the acquisition of continuous major septa - is a reversal of the lonsdaleoid trend of Lang (1923 p.127).

(ii) Distribution of the Caninioid Corals

There is a definite order of appearance of the caninioid corals in the Dinantian of the S.W.Province.

C. cornucopiae enters first, followed by *C. patulum* and *C. cylindrica*. Throughout Pembrokeshire *C. cornucopiae* is recorded near the base of the Tournaisian Main Limestone and continues to the upper part of the Viséan. *C. patulum* is confined to the Tournaisian Main Limestone in Pembrokeshire. It enters 650 feet below the top of the Tournaisian in the Bosherston outcrop and in the upper parts occasional loosely septate varieties, referred to *C.* aff. *patulum* by Smyth (1930), are to be found. It enters 400 feet below the top of the Tournaisian in the southern limb of the Pembroke Syncline, 500 feet in the Gower, 550 feet in the Mendips and 650 feet in Burrington Combe (where again it is replaced upwards by the loosely septate variety - Mitchell, personal communication). North of a line joining the Pembroke Syncline, the Gower and Burrington Combe *C. patulum* is not recorded in the Tournaisian.

The *C. cylindrica* group follows *C. patulum* higher in the succession in the S.W. Province. Usually it enters in the Tournaisian Main Limestone, except in the Bosherston outcrop where it first appears in the basal Viséan. Details

EXPLANATION OF PLATE XX1X

fig. 1 *Koninckophyllum linneyensis* sp.nov.

Transverse and longitudinal sections of the holotype. (All x 1)

Upper part of the Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

Fig. 2 *Auloclisia mutatum* Lewis

Transverse sections of same specimen (All x 1)

Upper part of the Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig. 3 *Auloclisia mutatum* Lewis

Transverse sections of mature and young stages of the same specimen (All x 1)

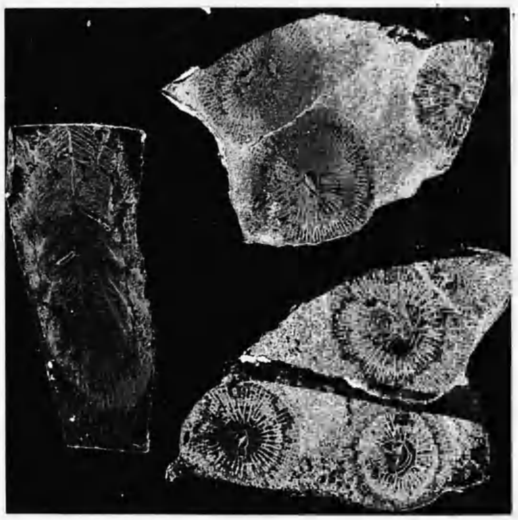
Upper part of the Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig. 4 *Cravenia lamellata* Howell

Transverse sections of same specimen (All x 1)

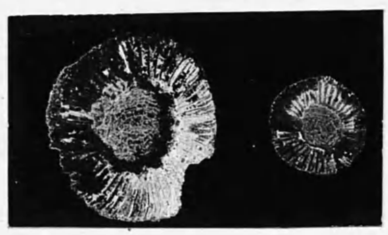
Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

1.



2.

3.



4.

of its incoming across the S.W.Province are not fully known but it enters about 100 feet above the incoming of _C.patulum_ in the southern limb of the Pembroke Syncline and 375 feet above in Burrington Combe. In the Pembroke Syncline _C.cylindrica_ continues into the Viséan but in Burrington Combe it is confined to the Tournaisian.

C.caninoides and _C.archiaci_ appear to be typical Viséan forms in Pembrokeshire. The former species appears to be diagnostic and restricted to the Upper _Caninia_ Zone. _C.archiaci_ appears in the uppermost beds of the Upper _Caninia_ Zone in the Bosherston outcrop.

(2) Description of Corals (other than the Caninioid Corals)

Koninckophyllum linneyensis sp.nov.

Pl. XXIX fig. 1

Diagnosis

Compound _Koninckophyllum_ with long major septa extending to the centre and with minor septa at least half the length of the major ones. Dissepimentarium wide with fine concentric dissepiments. Tabularium almost devoid of tabulae. Dilated medial plate usually present surrounded by a few concentric tabellae.

Description of Holotype

Compound, phaceloid Koninckophyllum which increases by lateral budding. The component corallites touch in places. The individual corallite is long and slender. The septa are of two series, the major ones are long and almost reach the centre, the minor septa are at least half the length of the major ones. There are 40 major septa at a diameter of 15 mm. Both major and minor septa extend to the epitheca. The dissepimentarium is wide, just a little less than the length of the minor septa, and made up of 5-6 rows of concentric closely-set dissepiments. The tabulae are few in number.

The dilated medial plate is well developed and is continuous with the counter and cardinal septum. When the septa retreat a little from the centre the medial plate is often surrounded by a few concentric tabellae.

In longitudinal section the medial plate is seen to be flanked by domed-up tabulae which are clearly marked off from the closely set dissepiments.

Dimensions of Holotype

Diameter = 15 mm.	Major septa = 40
Diameter = 17 mm.	Major septa = 43
Diameter = 20 mm.	Major septa = 46

Comparison and affinities

The only compound Koninckophyllids hitherto recorded are K.dianthoides (McCoy) (Hill 1938 pp.96-97, pl. IV figs.14-16) and K.echinatum (Thomson) (Hill 1938 pp.97-98, pl.IV figs.19-23 and pl.V figs.1 and 2). They differ markedly from the Pembrokeshire species - the former occurring as pyramidal masses and the latter losing its axial column at an early stage. K.dianthoides is a Viséan form in N.W.England and K.echinatum a Viséan form from Scotland.

The Pembrokeshire species is closely comparable to Koninckophyllum θ (Vaughan) (1905 p.282 pl.XXIII fig.4) in the septal arrangement and the thickened medial plate with only occasional major septa extending to the centre. Koninckophyllum θ has, however, never been found compound. Moreover, it is recorded in the Dibunophyllum Zone of the S.W.Province while the Pembrokeshire species if found in the Upper Caninia Zone.

EXPLANATION OF PLATE XXX

fig. 1 *Koninckophyllum cf. praecursor* Howell

Transverse and longitudinal section of large specimen showing the loss of medial plate in mature stage (All x 1)

Upper part of the Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig. 2 *Koninckophyllum praecursor* Howell

Transverse sections of "Koninckophylloid" variant (All x 1)

Lower part of the Upper *Caninia* Zone, Hanging Tar, Bosherston outcrop.

fig. 3 *Koninckophyllum praecursor* Howell

Transverse and longitudinal section of "Carrutherselloid" variant. (All x 1)

Upper part of the Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig. 4 *Koninckophyllum praecursor* Howell

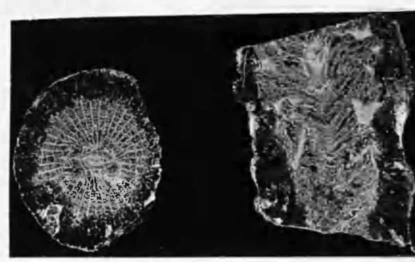
a & b. Transverse sections of "Carrutherselloid" variant. (All x 1)

Lower part of Upper *Caninia* Zone, above reef, Stackpole Quay, Bosherston outcrop.

1.

2.

3.



4 a.

b.

The Pembrokeshire species also resembles K.cyathophylloides (Vaughan) (1906 p.319 pl.XXX fig.1 and Smyth 1937 p.187) but differs from Vaughan's species in being compound, having a thickened medial plate with very few septal lamellae and fewer dissepiments.

Horizon

Recorded from the Upper Caninia Zone (Group 9, Dixon 1921 p.130) near the Wash, east of Linney Head, Bosherston outcrop.

Koninckophyllum praecursor Howell.

Pl. XXX figs. 1-4

Howell (1938 p.10 pl.I figs.10-22) describes and illustrates K.praecursor from the Caninia Oolite and Upper Caninia Zone of Gower. The Pembrokeshire specimens are closely comparable in their long, closely-set septa. The major septa number 40-45 at a diameter of 20 mms. The minor septa are about half the length of the major ones. There are 8-10 rows of dissepiments. The major septa meet distally at the axial structure. The axial structure is compact, fusiform, elongated in the direction of the cardinal and counter septum, and made up of numerous radial lamellae. The Pembrokeshire specimens show both the "Carrutherselloid" (pl XXX fig.3) and "Koninckophylloid" variants (pl.XXX fig. 2).

In longitudinal section the axial column is made up of a thin medial plate and steeply crowded tabellae. The compound tabulae are fewer in number, less highly inclined, and terminate against the axial column. The dissepiments are closely set and vary much in inclination.

<u>Remarks</u>

Small-scale lateral budding is seen near the base of one of the corallites.

<u>Horizon</u>

It is found in Pembrokeshire in the lower part of the Upper <u>Caninia</u> Zone overlying the reef in the Linney Head area, Bosherston outcrop.

<u>Auloclisia mutatum</u> (Lewis)

Pl. XXIX figs. 2 and 3

<u>A. mutatum</u> is described by Lewis (1927 p.31 pl.I figs.1a-h, pl.II figs.1a,b) from the <u>Dibunophyllum</u> Zone of the Isle of Man. The Pembrokeshire specimens are very similar in having 65 septa at a diameter of 35 mm;

the major septa are long and thickened but do not quite reach the central column. The minor septa are also thickened and vary in length from a quarter to half the length of the major ones. The cardinal fossula is well defined. The dissepiments in the adult stage are numerous and arranged in 5-6 concentric rows. The ratio of the dissepimentarium : tabularium : central column is 1:2:3.

The central column is a dense rounded structure made up of arched tabellae and crossed by septal lamellae. In longitudinal section, 20-25 closely packed tabellae occur in 1 cm. and are bounded by a distinct wall. A medial plate is developed in the young stage.

The Pembrokeshire specimens were named Clisiophyllum aff. omaliusi by Vaughan in the Survey Collection (E.D.2013).

Horizon

Recorded from the Upper Caninia Zone of the Bosherston outcrop.

<u>Cravenia lamellata</u> Howell.

Pl. XXIX fig. 4

The Pembrokeshire specimens are conspecific with <u>C.lamellata</u> illustrated and described by Howell (1938 p.2 pl.I,figs.1-4) from the Upper <u>Caninia</u> Zone of the Gower. They are small solitary corals with 40 long major septa at a diameter of 15 mm. which increases to 55 septa at a diameter of 25 mm. The minor septa are small, there are no dissepiments, and very few tabulae.

The axial structure is large and well defined, and is composed of a thin medial plate, radial lamellae, and numerous tabellae. Cardinal fossula is well marked.

In the Survey Collection, <u>C.lamellata</u> was named " <u>?C.patula</u> or <u>Cyathophyllum</u> " by Vaughan (E.D.1988).

<u>Horizon</u>

Upper <u>Caninia</u> Zone of the Bosherston outcrop.

EXPLANATION OF PLATE XXXI

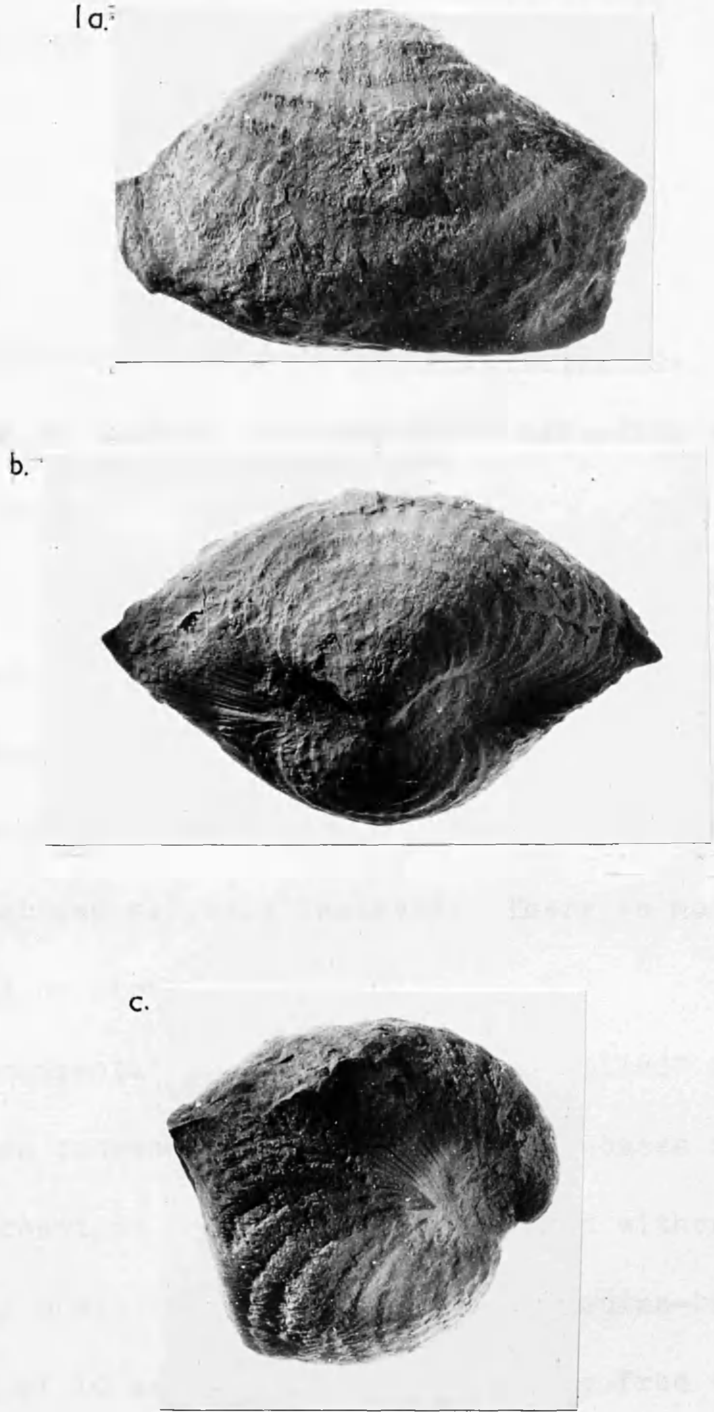
Phricidothyris sp.nov.

fig. a. Ventral view

b. Posterior view of same specimen

c. Lateral view of same specimen
(All x 1)

Upper *Caninia* Zone, Pen-y-holt Bay,
Bosherston outcrop.


1a.
b.
c.

3. Description of brachiopods

Phricodothyris sp. nov.

Pl. XXXI fig. 1 a-c

Description

A transverse tumid form of Phricodothyris, subcircular in outline with the width exceeding the length of the shell. The hinge-line is long and straight but slightly less than the greatest width. The cardinal area is long and low with a fine striate ornamentation parallel with the hinge-line. The cardinal extremities are rounded. The ventral umbo is prominent and slightly incurved. There is no mesial fold or sinus.

The ornamentation is of "double barrelled" spine-bases set on concentric rugae. The spine-bases are of fairly constant size, evenly spaced and without intervening pustules. There are about 9 spine-bases in a width of 10 mm., at a distance 10 mm. from the umbo.

Comparison and affinities

It is readily distinguished from the phricodothyrids /

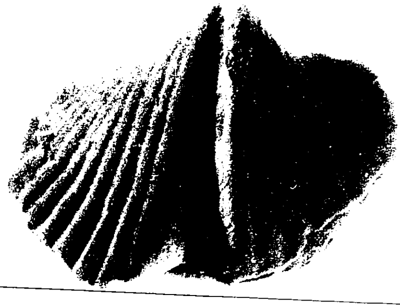
EXPLANATION OF PLATE XXXII

Spirifer dixoni sp.nov.

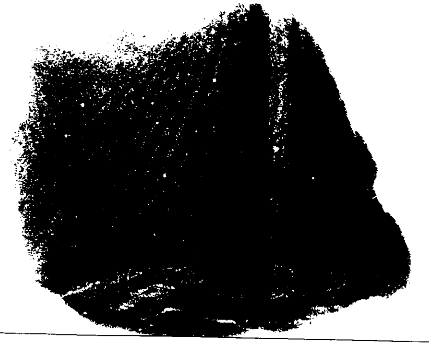
fig.1	Ventral view of holotype (x 3)
figs.2-4	Ventral views of typical forms (All x 3)
fig.5	Dorsal view of specimen showing almost smooth fold. (x 3)
fig.6	Ventral view of large specimen showing faint costae on the sinus (x 2)

Upper Caninia Zone, near Pen-y-holt Bay
Bosherston outcrop.

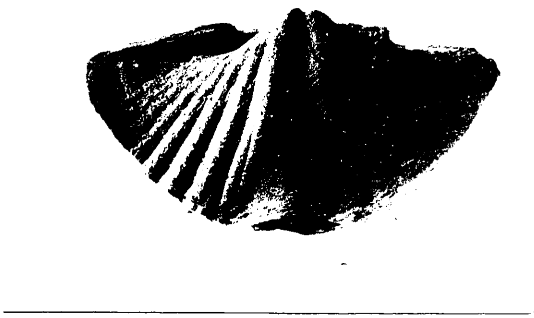
1.



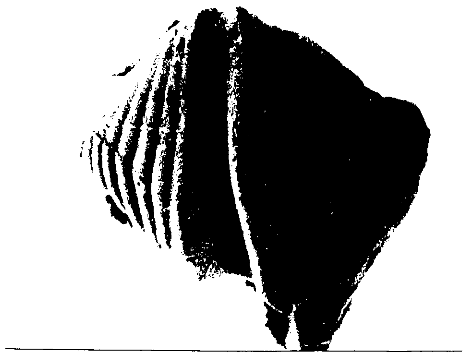
2.



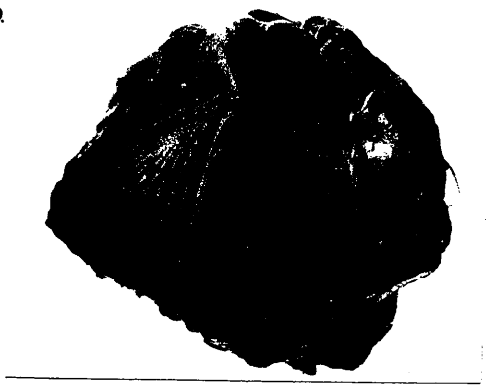
3.



4.



5.



6.

illustrated by George (1932) by its extremely transverse and tumid shape and coarse ornamentation. The Pembrokeshire specimens were referred to Reticularia cf. imbricata (J. Sowerby) in the Geological Survey Collection (J.M. 999).

Horizon

Only 4 specimens have been found and they were recorded from the Upper Caninia Zone (Group 7 of Dixon 1921 p.130) of the Bosherston outcrop.

Spirifer dixoni sp. nov.

Pl. XXII figs. 1-6

Diagnosis

Shell small, valves biconvex, transverse, nearly twice as wide as long, hinge-line the greatest width of the shell, cardinal extremities pointed and extended, ventral valve with a deep narrow sinus with 3 or 4 very faint costae, the dorsal valve with a prominent fold, umbo acute, elevated and incurved.

Description of holotype

Small transverse ventral valve with the hinge-line being the greatest width of the shell. The cardinal /

extremities are pointed and extended. The cardinal area is long and narrow, tapering towards the cardinal extremities. The ventral umbo is prominent, pointed and acute, slightly incurved over the cardinal area. The ventral sinus extends from the umbo to the anterior margin and is deep and widens anteriorly. The sinus is almost smooth but for 3 faint costae which appear on the anterior part. The surface of the shell has 12 prominent narrow costae on each lateral slope, separated from each other by a narrow groove. The two costae demarcating the sinus are the thickest and most prominent. The costae never bifurcate and are ornamentated with faint concentric striae.

Dimensions of holotype

Length = 14 mm. approx. Width = 18 mm.

Variations

Some specimens are more transverse than the holotype (pl.XXII fig.3) while others are larger with a more rounded sinus which shows the costae more clearly defined (pl.XXII fig.6).

EXPLANATION OF PLATE XXXIII

fig.1 Smooth Spiriferoid gen and sp.nov.

a. Ventral view

b. Posterior view of same specimen showing high cardinal area and prominent umbo. (All x 3)

Upper Caninia Zone, near Pen-y-holt Bay, Bosherston outcrop.

fig.2 Spirifer cf.konincki (Dewalque)

Ventral View (x 1)

Upper Caninia Zone, near the Wash, Bosherston outcrop.

fig.3 Spirifer cf.konincki (Dewalque)

Ventral view (x 1)

Upper Caninia Zone, Pen-y-holt Bay, Bosherston outcrop.

fig.4 Spiriferellina octoplicata (Sowerby)

Ventral view (x 3)

Upper Caninia Zone, Pen-y-holt Bay, Bosherston outcrop

fig.5 Spiriferellina cf. octoplicata (Sowerby)

Dorsal view (x 3)

Upper Caninia Zone, Stackpole Quay, Bosherston outcrop.

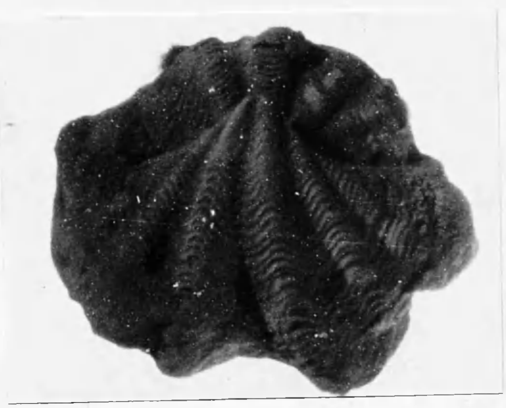
1 a.

b.

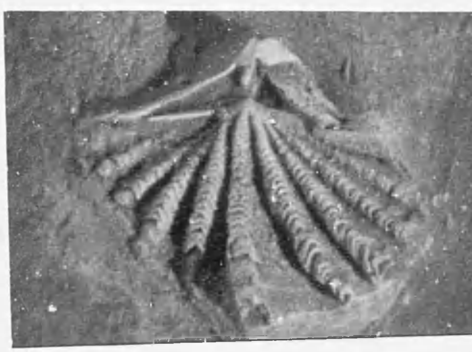
2

3

4.



5.



Comparison and affinities

It is named Spirifer aff. clathratus (McCoy) in the Survey Collection (J.M. 970, 1007, 1025). Its small size, transverse shape, deep and almost smooth sinus and prominent fold distinguish the Pembrokeshire species from such transverse Spirifers as Spirifer tornacensis (de Koninck) and Spirifer pinskeyensis (Garwood).

Horizon

The species is abundant in the thick mudstone (Group 6 of Dixon 1921 p.130) of the Upper Caninia Zone in the Bosherston outcrop. The holotype was collected from the thick mudstone near Pen-y-holt Bay south-east of Linney Head.

Smooth Spiriferoid genus and species nov.

Pl.XXXIII figs.1 a-b

Description

Small smooth spiriferoid with extremely high cardinal area and prominent incurved umbo. The shell is a little wider than long, the hinge-line is slightly less than the greatest width of the shell. The cardinal extremities are rounded.

Dimensions

Length = 13 mm. Width = 14 mm.

Comparison and affinities

It resembles Ambothyris and Crurithyris (George 1931) but is distinguished by the extremely high cardinal area.

Only three fragmentary specimens have been found and the material is too poor to designate a new genus or species.

Horizon

It is recorded from the middle of the Upper Caninia Zone (Group 7 of Dixon 1921 p,130), in Cabin Door Bay, southeast of Linney Head.

Spirifer cf. konincki (Dewalque)

Pl. XXXIII figs. 2-3

The Pembrokeshire specimens are identical with Spirifer konincki illustrated by Delépine (1930 p.16 pl.II fig.4). They agree in being large, semicircular with markedly bifurcating costae on the anterior parts of the fold and flank, and fine reticulate striae on the costae. The costae number approximately 9 on the fold, 20-25 on the flank.

The form is also very similar to *Spirifer konincki* illustrated by Douglas (1909 p.574, pl.XXVI figs.la and lb) but it is distinguished by the absence of the broad costae dividing the sinus.

Vaughan (1915 pp 15, 27 and 42) referred these large Pembrokeshire spiriferoids to *Spirifer suavis* (de Koninck) and it is likely that these two species are conspecific. In addition, Delepine (1930 pp.16-17) considered *Spirifer konincki* to be conspecific with *Spirifer subcinctus* (de Koninck) and *Spirifer cinctus* (de Koninck). The latter view was also supported by Dewalque (1895 p.XLVI).

Spirifer konincki (Dewalque) differs from *Spirifer tornacensis* (de Koninck), with which it is often confused, by being less transverse and in the marked bifurcation of the costae anteriorly.

Horizon

As in Belgium, *Spirifer konincki* appears in the Tournaisian Main Limestone in Pembrokeshire and continues /

into the lower Viséan. It is particularly abundant in the upper part of the Tournaisian Main Limestone in the Bosherston and Pembroke outcrops. Smyth (1930) referred this species to Spirifer aff. princeps (McCoy) at Hook Head and also noted its abundance in the upper part of the Tournaisian.

Spiriferina octoplicata (Sowerby)
and related forms

Pl. XXXIII figs. 4-5

The forms referred to this species in Pembrokeshire agree with Spiriferina octoplicata illustrated by Sowerby (1823 t.DLXII figs.2 and 3 non fig.4) and by North (1920 p.215 pl.XII figs.8 and 9). The valves are semicircular, equally convex, with rounded cardinal extremities. 3 to 4 angular costae are developed on the lateral flanks, which are smaller in size than the prominent mesial fold and sinus.

One specimen collected from the Upper Caninia Zone of Stackpole Quay (pl.XXXIII fig. 5) differs from Sowerby's species in having the fold and costae of

EXPLANATION OF PLATE XXXIV

fig.1 *Dictyoclostus sp*. (coarsely costate variety)

a. Ventral view

b. Lateral view of same specimen (All x $1\frac{1}{2}$)

Upper *Caninia* Zone, west of the Wash, Bosherston outcrop.

fig.2 *Dictyoclostus sp*. (finely costate variety)

Upper *Caninia* Zone, west of the Wash, Bosherston outcrop.

1a.

b.

2a.

b.

equal size. In this it agrees with Demanet's interpretation of *Spiriferina octoplicata* (1931).

Horizon

The form occurs commonly in the Tournaisian of Pembrokeshire. It is particularly abundant in the Bosherston outcrop where it continues into the Upper *Caninia* Zone.

Dictyoclostus sp.

Pl. XXXIV figs. 1-2

Dictyoclostids are extremely abundant in the Upper *Caninia* Zone of the Bosherston outcrop. In the Survey Collection the large forms have been referred to *Dictyoclostus pugilis* (Phillips) - early form (E.D. 1223 and J.M. 810) and the small forms to *Dictyoclostus bristolensis* (Muir Wood) (E.D. 1306) and *Productus* cf. *garwoodi* (Muir Wood) (E.D. 1582 and 1592) by Muir Wood and Stubblefield.

A close examination of a large number of specimens suggests that they may be assigned to two distinct groups based not on size but on ornamentation.

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1. Finely costate variety (Pl. XXXIV fig. 1)

Of the two groups this form approaches closer to D. pugilis as illustrated by Muir Wood (1928 p.133 pl.IX figs.1-5). It agrees in being quadrate in outline with a globose pedicle valve and curved trail and the broad and often sinuated venter. The costae are fine, about 18 in 10 mm. at 15 mm. from the umbo. The ribs are coarse on the cardinal flanks and are traceable across the front of the visceral disk.

It differs, however, from D. pugilis in the greatest width being anterior to the hinge-line and not at the hinge-line. Moreover, the Pembrokeshire forms are less elongated, the height being equal to the width (1:1:0·6), while in D. pugilis the height exceeds the width (1:0·8:0·6).

Young examples are similar to D. bristolensis illustrated by Muir Wood (1928 p.140 pl.IX figs.7a and b) from the Tournaisian of the Bristol area. However, in the Tournaisian species the costae are much coarser, about 12 in 10 mm. at 20 mm. from the umbo as compared to 18 in the species under discussion.

It is readily distinguished from P. garwoodi in the absence of a diaphragm.

2. Coarsely-costate variety (Pl.XXXIV fig. 2)

This is the common form in the Upper Caninia Zone of the Bosherston outcrop. It is fairly large, typical dimensions being 50 mm. in height, 52 mm. wide and 27 mm. in thickness (1:1·1:0·6). It is quadrate in outline, the hinge-line is slightly less than the greatest width of the shell, and the ventral margin is often sinuated. The costae are fairly coarse, 12 to 14 in 10 mm. at 15 mm. from the umbo and constitute the most important feature distinguishing them from the group discussed above. The costae increase in prominence anteriorly. The concentric ribbing is also coarse and easily traced around the visceral disk. Small spine-bases are scattered over the shell.

This coarsely-costate variety differs from the forms illustrated by Muir Wood as D. pugilis in being more transverse, in the absence of longitudinal folds on the anterior part of the shell, and in the coarser ornamentation.

EXPLANATION OF PLATE XXXV

fig.1 Dictyoclostus cf. teres (Muir Wood)

a. Ventral view

b. Lateral view of same specimen (All x 3)

Upper Caninia Zone, near Pen-y-holt Bay,
Bosherston outcrop

fig.2 Pustula cf. interrupta (Thomas)

Ventral view (x 1)

Upper Caninia Zone, near the Wash,
Bosherston outcrop

fig.3 Echinoconchus punctatus (Martin)

Ventral view (x 1)

Upper Caninia Zone, near the Wash,
Bosherston outcrop.

1a.

b.

2.

3.

Young forms are very similar to D. bristolensis and cannot be readily distinguished from it.

Horizon

D. pugilis is a Dibunophyllum Zone form from Scotland and the Northwest of England. The Pembrokeshire forms are restricted to the Upper Caninia Zone of the Bosherston outcrop.

Dictyoclostus cf. teres (Muir Wood)

Pl. XXXV fig. 1 a-b

Small form, shell about 20 mm. high, 18 mm. wide, 12 mm. thick or 1:0·9:0·6. It is elongate with the greatest width occurring anterior to the hinge-line. The trail is curved. Costae moderately coarse, about 17 to 19 in 10 mm. at 10 mm. from the umbo. Ribs numerous on cardinal slopes. Spine-bases large and irregularly scattered on the trail.

It is comparable with D. teres illustrated by Muir Wood (1928 p.87 pl. III figs.9a and b). The Pembrokeshire form is difficult to distinguish from Dictyoclostus vaughani (Muir Wood 1928 pl.II figs. 12a-c) but it differs in being less transverse, and having a less globose visceral disk, a more curving trail and coarser costation.

Horizon

The holotype of D.teres comes from the "C_1" Zone of the N.W. Province. The Pembrokeshire forms occur abundantly through the top of the Tournaisian Main Limestone and Upper Caninia Zone of the Bosherston outcrop and Pembroke Syncline. Similar forms referred to D.teres are also recorded abundantly from the upper part of the Michelinia favosa beds to the top of the succession exposed at Hook Head (Smyth 1930 p.543).

This form is referred to Productus burlingtonensis-concinnus by Vaughan in the Survey Collection (E.D.2007).

Pustula cf. interrupta (Thomas)

Pl.XXXV fig. 2

Thomas (1914 p.276) referred the forms from the Upper Caninia Zone of the Bosherston outcrop to Pustula interrupta mainly on the ornamentation. It consists of well-marked concentric bands with

EXPLANATION OF PLATE XXXVI

fig.1 *Schizophoria resupinata* (Martin)

Dorsal view (x 1)

Upper *Caninia* Zone, near Pen-y-holt Bay, Bosherston outcrop.

fig.2 *Schizophoria resupinata var.gigantea* (Demanet)

Dorsal view (x 1)

Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig.3 *Schizophoria resupinata* (Martin)

Dorsal view (x 2)

Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop.

fig.4 *Schizophoria resupinata var.lata* (Demanet)

Dorsal view (x 3)

Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop.

1.

2.

3.

4.

elongated spine-bases and occasional shorter spine-bases in front of them. In addition, it is similar to P. interrupta illustrated by Thomas (1914 pl.XX fig.5) in its broad, ill-defined sinus in the ventral valve. However, the Pembrokeshire forms are much broader and the concentric bands become more crowded on the anterior part of the shell and resembles Pustula pilosa (Thomas) (1914 pl.XX fig.3).

Horizon

Pustula cf. interrupta occurs abundantly in the Tournaisian Main Limestone and Upper Caninia Zone of the Bosherston outcrop.

Schizophoria resupinata (Martin)

Pl.XXXVI figs. 1-4

In the "zaphrentid phase" limestones of the Bosherston outcrop Schizophoria resupinata is particularly common. The specimens are closely comparable to those illustrated by Davidson (1858-63 pl.XXIX figs.1-4) and Demanet (1934 pl.III figs.1-5). They are suboval in shape, the hinge-line is straight and much shorter than the greatest width of the shell. Typically the specimens are transverse, the dorsal valve is regularly convex and the ventral valve is only slightly convex near the umbo and flattens anteriorly. The shell is ornamented by fine costae and scattered spine-bases.

Together with the typical S. resupinata in the Tournaisian Main Limestone more transverse forms occur which are comparable to S. resupinata var. lata Demanet (1934 p.50 pl.III figs.6-8). In the Viséan large varieties of S.resupinata are recorded (some exceed 6 cm. in length) and they are referred to S.resupinata var.gigantea Demanet (1934 p.60 pl.IV figs.12 and 13).

In the Survey Collection S.resupinata var lata (E.D. 1272) is also recorded from the Upper Caninia Zone.

Horizon

S.resupinata is extremely common in the Tournaisian of Pembrokeshire and in the extreme south, under "zaphrentid phase" conditions, they continue

EXPLANATION OF PLATE XXXVII

fig.1 Schellwienella aspis mut.radialiformis (Demanet)

Dorsal view (x 2)

Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop.

fig.2 Schellwienella aspis mut.radialiformis (Demanet)

Dorsal view (x 1½)

Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop.

fig.3 Schuchertella cf. fascifera (Tornquist)

Dorsal view (x 1)

Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig.4 Schuchertella cf. fascifera (Tornquist)

Interior of ventral valve (x 1)

Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig.5 Derbya sp.

Interior of dorsal valve (x 1)

Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

fig.6 Orthetetes sp.

Interior of dorsal valve (x 2)

Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

1.

2.

3.

4.

5.

6.

abundantly into the Viséan. In Belgium Demanet (1934 pp.104-105) recorded S.resupinata throughout the Dinantian. He further recorded S.resupinata var. gigantea from the D_1 of Belgium and S.resupinata var. lata from C_1 and C_2S_1.

Schellwienella aspis Smyth

Pl. XXXVII figs. 1-2

This form is the common orthotetid in the Tournaisian Main Limestone and appears to be more or less confined to it. It is very similar to the form illustrated by Smyth (1930 p.553 pl.XV figs.1-4) in its resupinate ventral valve, regularly convex dorsal valve and semicircular shape. It is wider than long and has acute cardinal angles. The ornamentation is caracteristically fine and regular, the costae are sharp and closely spaced and multiply by intercalation.

A form also occurs in the Tournaisian Main Limestone which is referred by the author to S.aspis mut.radialiformis Demanet (1934 p.85 pl.VII figs.6-12). It differs from Smyth's species in ornamentation, the radial costae tending to become coarser and the fourth costa in each series more pronounced. Also the form tends to become larger in size.

Horizon

S.aspis and *S.aspis mut.radialiformis* both occur in the Tournaisian Main Limestone in the Bosherston outcrop. However, *S.aspis* is the dominant form in the lower parts of the Tournaisian Main Limestone and *S.aspis mut.radialiformis* in the upper parts of the group. Moreover, occasional forms of *S.aspis mut.radialiformis* continue into the Viséan.

Smyth (1930 p.585) also noted this upward variation in the Tournaisian of Hook Head and referred the higher form to *S.aff.aspis* (pl.XVI fig.6).

Schuchertella cf. fascifera (Törnquist)

Pl. XXXVII figs. 3-4

This is the dominant orthetetid in the Upper *Caninia* Zone in the Bosherston outcrop. It is a large form measuring $6\frac{1}{2}$ cm. in length and 10 cm. in width. It is very depressed, concavo-convex, much wider than long and the greatest width occurs at the hinge-line.

Externally, the ornamentation consists of fine regular costae havin g the same thickness from the umbo to the anterior margins of the shell. The interval between the major costae is approximately three times their own width. Finer costae, 2 to 4 in number and visible only with close inspection, are intercalated between the major ones. In addition, extremely fine concentric undulations numbering 25 or more in 1 cm. are developed in the inter-spaces between the costae, often masking the finer costae.

One example of a ventral valve (pl.XXXVII fig. 4) shows the faint ridge limiting the scars of the divaricator muscles; a medium pseudo septum is also developed. These features are also seen in Schuchertella wexfordensis Smyth (Davidson 1856-63 pl.XXVI fig.5, Thomas 1910 p.101, Smyth 1930 p.555 pl.XV figs. 8 and 9). The cardinal area is long and transversely striated, with only rudimentary delthyrial supporting plates in the ventral valve. A large quadrilobed cardinal process is to be seen

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in the dorsal valve.

The Pembrokeshire specimens are closely comparable with those illustrated and described by Paeckelmann (1930 pl.12 figs.3a and 3b), Demanet (1934 p.91 pl.VIII figs.5-7) and Cowper Reed (1954 p.184 pl.I fig.5).

It is readily distinguished from <u>Schuchertella wexfordensis</u> Smyth by its larger size and ornamentation. In Smyth's species the costae are closer set and regular in strength.

It is recorded as <u>Schuchertella</u> sp. in the Survey Collection (E.D.1650 and 1651).

<u>Horizon</u>

It is recorded from the upper Tournaisian Main Limestone of the Bosherston outcrop and Pembroke Syncline and continues into the Visean in the former.

In Belgium, Demanet recorded it from the upper part of the Tournaisian to the top of the Viséan. Cowper Reed recorded it from the Charlestown Main Limestone, Roscobie, Scotland.

EXPLANATION OF PLATE XXXVIII

fig. 1 *Daviesiella carinata* (Garwood)

Ventral view (x 1)

Upper *Caninia* Zone, Caldy Island, Pembroke Syncline

fig. 2 *Cleiothyridina hibernica* (Douglas)

Dorsal view (x 2)

Tournaisian Main Limestone, Blucks Pool, Bosherston outcrop.

fig. 3 *Actinoconchus lamellosus* (Leveille)

Ventral view (x 1)

Upper *Caninia* Zone, near the Wash, Bosherston outcrop.

1.

2.

3.

IX FAUNAL LISTS

The following lists are based on (1) the fossils collected by the author, (2) the fossils in the Geological Survey Collection, listed by Dixon (1921 pp.73-82 and in Strahan and others 1914 p.143) and re-examined by the author.

The faunal lists are compiled under the following headings

1. The comparison of the fauna of the Tournaisian Main Limestone of Pembrokeshire
2. The comparison of the fauna of the Upper *Caninia* Zone of Pembrokeshire
3. Bosherston Outcrop
4. Pembroke Syncline
5. Tenby Outcrop
6. West Williamston Outcrop
7. North Crop

1. The comparison of the fauna of the Tournaisian Main Limestone of Pembrokeshire

The columns are named as follows:

B. Bosherston Outcrop
P.S. Pembroke Syncline
T. Tenby Syncline
W.W. West Williamston Outcrop
N.C. North Crop

	B.	P.S.	T.	W.W.	N.C.
Allotropiophyllum	x	x			
Amplexus	x	x			
Caninia cornucopiae	x	x	x		
" cylindrica group		x			
Caninophyllum patulum	x	x			
Cryptophyllum	x				
Cyathaxonia	x				
Koninckophyllum	x	x			
Rotiophyllum	x	x	x	?	?
Zaphrentites	x	x	?	?	?
Cladochonus	x				
Emmonsia	x				
Michelinia	x	x	x		
Syringopora	x	x	x		
Actinoconchus	x	x		x	x
Argentiproductus	x	x			
Avonia bassa		x		x	x
Buxtonia		x		x	
Camarotoechia mitcheldeanensis		x	x	x	x
Cleiothyridinia	x	x	x	x	x
Dictyoclostus vaughani	x	x	x	x	x
Eomarginifera	x				
Leptaena analoga	x	x	x	x	x
Megachonetes		x	x		
Pustulids	x	x			x
Rhipidomella michelini	x	x	x	x	x
Rugosochonetes	x	x	x	x	x
Schellwienella aspis and related forms	x				
Schellwienella crenistria		x	x	x	x
Schizophoria resupinata and related forms	x	x	x		x
Schuchertella cf.fascifera	x	x			
" wexfordensis		x			
Spirifer cf. konincki	x	x			
" tornacensis group	x	x	x	x	x
Spiriferellina octoplicata and related forms	x	x			x
Syringothyris	x	x			x
Tylothyris cf.laminosa	x	x	x		

2. <u>The comparison of the fauna of the Upper Caninia Zone</u>

The columns are named as in (1)

	B.	P.S.	T.	W.W.	N.C.
Allotropiophyllum	x				
Amplexus	x				
Amplizaphrentis aff.enniskilleni	x	x			
Auloclisia mutatum	x				
Caninia caninoides	x	x			
" cornucopiae	x				
" cylindrica group	x	x			
Caninophyllum archiaci	x				
Carcinophyllum sp.		x	x		
Cravenia lamellata	x				
Cryptophyllum hibernicum	x				
Cyathaxonia	x				
Koninckophyllum	x				
Lithostrotion	x	x	x		
Palaeosmilia murchisoni		x	x		
Rotiophyllum	x				
Zaphrentites	x	x			
Cladochonus	x				
Emmonsia	x				
Michelinia	x	x	x		
Syringopora	x	x	x		
Actinoconchus	x	x			
Argentiproductus	x				
Avonia	x				
Camarotoechia	x	x			
Cleiothyridina	x	x			
Daviesiella carinata		x			
" comoides	x	x	x		
" destinezi	x	x			
Dictyoclostus	x	x	x		
Dielasma	x	x	x		
Echinoconchus	x	x			
Eomarginifera	x				
Giganto productus	x	x			
Krotovia	x	x			
Leptaena analoga and related forms	x	x			
Linoproductus	x	x	x		
Martinia		x			
Megachonetes	x	x			
Orthetetes	x				
Overtonia	x				
Phricodothyris	x				
Plicatifera	x				
Pliochonetes	x				

	B.	P.S.	T.	W.W.	N.C.
Pugnax	x				
Pustula	x	x			
Reticularia	x	x			
Rhipidomella michelini	x	x			
Schellwienella	x	x	x		
Schizophoria resupinata and related forms	x	x	x		
Schuchertella	x				
Spirifer dixoni	x				
" cf. konincki	x	x			
" tornacensis group	x				
Spiriferellina octoplicata and related forms	x				
Syringothyris	x	x	x		
Tylothyris cf. laminosa	x				

3. Faunal list for the Bosherston Outcrop

The columns are named as follows:

L.T. Lower part of Tournaisian Main Limestone comprising Groups 1-3 of Dixon (1921 pp.123 and 124)

U.T. Upper part of Tournaisian Main Limestone Groups 8-12 of Dixon (1921 p.123) and Groups 1 and 2 (1921 p.127)

$L.C_2S_1$ Lower part of the Upper *Syringothyris* subzone (Groups 1-5) of Dixon (1921 pp.130-131)

$U.C_2S_1$ Upper part of Upper *Syringothyris* subzone and the Lower *Seminula* subzone (Groups 6-9) of Dixon (1921 p.130)

S_2 Upper *Seminula* subzone (Group 10) of Dixon (1921 p.130)

(a) Rugose corals

	L.T.	U.T.	$L.C_2S_1$	$U.C_2S_1$	S_2
Allotropiophyllum burringtonense (Vaughan)		x	x	x	
Allotropiophyllum spinosum (de Koninck)[1]		x	x	x	
Amplexus coralloides J.Sowerby[1]		x	x	x	
Amplexizaphrentis aff. enniskilleni Edward & Haime[1]			x		
Auloclisia mutatum Lewis				x	
Caninia caninoides Sibly[1]			x	x	
" cornucopiae Michelin[1]	x	x	x	x	
" cylindrica (Scouler)[1] -benburbensis (Lewis) Group			x	x	x
" sp.[1]			x	x	
Caninophyllum patulum Michelin[1]		x			
" archiaei Edward & Haime				x	
Carcinophyllum sp.[1]					x
Cravenia lamellata Howell				x	
Cravenia sp.		x			
Cryptophyllum hibernicum Carruthers[1]		x	x	x	
Cyathaxonia cornu Michelin[1]		x	x	x	
Koninckophyllum cf. cyathophylloides Vaughan[1]				x	x
Koninckophyllum linneyensis sp.nov.				x	
" praecursor Howell			x	x	
" aff.tortuosum Michelin[1]		x	x	x	

	L.T.	U.T.	L.C_2S_1	U.C_2S_1	S_2
Koninckophyllum sp.			x		
Lithostrotion cf. martini Edward & Haime			x	x	
Lithostrotion cf. pauciradiale (McCoy)				x	
Rotiophyllum ambiguum Carruthers		x	x	x	
" costatum (McCoy)		x	x		
" densum Carruthers	x	x	x		
" omaliusi Edward & Haime	x	x	x	x	
" rushianum (Vaughan)			x		
Zaphrentites delanouei Edward & Haime	x	x			
" konincki Edward & Haime	x	x			
" konincki var. kentensis Garwood			x		
" lawtonensis Carruthers				x	
" parallela Carruthers			x		

(b) Tabulate corals
see Dixon's faunal list
(1921 pp.74-76)

(c) Brachiopods

	L.T.	U.T.	L.C_2S_1	U.C_2S_1	S_2
Actinoconchus expansus (Phillips)		x			
" lamellosus (Léveillé) (see pl XXXVIII fig. 3)	x	x	x	x	
Actinoconchus planosulcatus (Phillips)		x	x	x	
Argentiproductus margaritaceus (Phillips)		x	x	x	
" pectenoides (Phillips		x	x	x	
Athyrids (undifferentiated)			x	x	
Avonia spp.		x		x	
Brachythyrid spiriferoid				x	
Camarotoechia pleurodon (Phillips)				x	
Cleiothyridina glabristria (Phillips)		x	x		
" hibernica Douglas		x	x		
" roissyi (Léveillé)	x	x	x	x	

	L.T.	U.T.	L.C_2S_1	U.C_2S_1	S_2
Composita ficoides (Vaughan)[1]					x
Davidsonina carbonaria[1] (McCoy)					x
Daviesiella comoides (Sowerby)[1]			x	x	
" destinezi (Vaughan)[1]			x	x	
Derbya sp.				x	
Dictyoclostus bristolensis Muir Wood[2]				x	
" cf.semireticulatus (Martin)		x			
" cf.teres (Muir Wood)		x	x	x	
" vaughani (Muir Wood)		x			
" spp.			x	x	x
Dielasma sp.[1]			x	x	x
Echinoconchus cf.elegans[1] (McCoy)				x	x
" punctatus (Martin)[1]				x	
Eomarginifera spp.		x	x	x	
Gigantoproductus cf. latissimus (J.Sowerby)				x	
Krotovia aculeatus (Martin)				x	
" spinulosa (Sowerby)			x	x	x
Leptaena analogia (Phillips) and related forms[1]	x	x	x	x	
Linoproductus hemisphericus (Sowerby)[1]				x	
" spp.[1]				x	x
Megachonetes spp.(broad papilionaceous forms)[1]				x	
Orthetetes sp.(see pl. XXXVII fig. 6)				x	
Orthetetids indet.[1]	x	x	x	x	
Overtonia fimbriata (J.de C. Sowerby)[1]			x	x	
Phricodothyris sp.nov.				x	
" sp.				x	
Plicatifera mesoloba (Phillips)		x		x	
" thomasi (Paeckelmann)				x	x
Pliochonetes cf.buchianus (de Koninck)				x	
Pugnax pugnus (Martin)[1]			x	x	
Pustula cf.interrupta (Thomas)[1]		x	x	x	

	L.T.	U.T.	$L.C_2S_1$	$U.C_2S_1$	S_2
Pustula cf.pyxidiformis (de Koninck)				x	
Reticularia sp.[1]				x	
Retzia (Hustedia) intermedia (de Koninck)[1]				x	
Rhipidomella michelini (Léveillé)[1]	x	x	x	x	x
" michelini var. divaricata Demanet			x	x	
Rhynchonellids undet.[1]	x	x	x	x	
Rugosochonetes cf.hardensis (Phillips)[1]	x	x	x	x	x
Schellwienella aspis Smyth		x			
" " mut. radialiformis Demanet		x			
" sp.			x		
Schizophoria resupinata (Martin)[1]	x	x	x	x	
" resupinata var. gigantea Demanet				x	
" resupinata var. lata Demanet		x		x	
Schuchertella cf.fascifera (Törnquist)		x	x	x	
Smooth spiriferoid genus nov.				x	
Spirifer dixoni sp.nov.			x	x	
" cf.konincki (Dewalque)		x	x	x	
" tornacensis (de Koninck) group	x	x	x		
" spp.		x	x	x	x
Spiriferellina octoplicata (Sowerby)[1]	x	x	x	x	
" cf.octoplicata (Sowerby)				x	
Syringothyrids undet.[1]	x	x	x	x	
Tylothyris cf.laminosa[1] (McCoy)	x	x	x	x	

Lamellibranchs, gasteropods, cephalopods etc. see Dixon (1921 pp.74,76,77,79-81)

Footnote

1. Also recorded by Dixon and included in the Faunal list (1921 pp.74-81)
2. Geological Survey Collection (E.D.1206) and named by Stubblefield.

4. Faunal list for the Pembroke Syncline

The columns are named as follows:

L.T. Lower part of Tournaisian Main Limestone comprising the *Zaphrentis* Zone of Dixon (1921 pp.99-100)

U.T. Upper part of Tournaisian Main Limestone comprising the Lower *Syringothyris* subzone of Dixon (1921 p.100)

C_2S_1 Upper *Syringothyris* and Lower *Seminula* subzones of Dixon (1921 p.101)

S_2 Upper *Seminula* subzone of Dixon (1921 p.102)

	L.T.	U.T.	C_2S_1	S_2
(a) Rugose corals				
Allotropiophyllum burringtonense (Vaughan)		x		
Amplexus cf. coralloides (J.Sowerby)		x		
Caninia caninoides Sibly			x	
" cornucopiae Michelin	x	x		
" cylindrica (Scouler) group		x	x	
Caninophyllum patulum Michelin		x		
Carcinophyllum sp.			x	x
Koninckophyllum sp.		x		
Lithostrotion basaltiforme (Phillips) Group				x
" martini (Edward and Haime)			x	x
" pauciradiale (McCoy)			x	
Palaeosmilia murchisoni (Edward and Haime)			x	
Rotiophyllum densum Carruthers		x		
" omaliusi Edward and Haime	x	x		
Zaphrentites delanouei Edward and Haime	x		x	
" aff.konincki Edward and Haime		x	x	
Zaphrentites sp.	x	x	x	
(b) Tabulate corals				
Michelinia cf.megastoma (Phillips)	x	x	x	
" cf.tenuisepta (Phillips)		x		
Syringopora cf.distans (Fischer de Wald.)			x	x
" cf.reticulata (Goldf.)		x		

(c) <u>Brachiopods</u>

	L.T.	U.T.	C_2S_1	S_2
Actinoconchus expansus (Phillips)[1]			x	
" lamellosus (Léveillé)[1]	x			
" planosulcatus (Phillips)[1]				x
Argentiproductus pectenoides (Martin)		x		
Athyrids (undifferentiated)[1]	x	x	x	x
Avonia bassa (Vaughan)[1]	x			
Buxtonia scrabicula (Martin)		x		
Camarotoechia mitcheldeanensis[1] (Vaughan)	x	x		
" cf.pleurodon (Phillips)[1]			x	
Cleiothyridina glabristria (Phillips)[1]	x			x
" roissyi (Léveillé)[1]	x	x	x	
Composita ficoides (Vaughan)[1]			x	x
Crancrinella undata (Defrance)			x	
Davidsonina carbonaria (McCoy)[1]				x
Daviesiella carinata (Garwood) (see pl. XXVIII fig. 1)			x	
Daviesiella comoides (Sowerby)[1]			x	x
" destinezi (Vaughan)			x	x
Derby bristollensis (Vaughan)[1]	x			
Dictyoclostus cf.teres (Muir Wood)			x	
" vaughani (Muir Wood)				
" sp.				
Dielasma hastate (Sowerby)[1]			x	
Echinoconchus elegans (McCoy)[1]			x	
" punctatus (Martin)[1]			x	
Gigantoproductus giganteus (Martin) Group[1]			x	x
Krotovia aculeatus (Martin)			x	
Leptaena analoga (Phillips) and related forms[1]	x	x	x	
Linoproductus corrugato-hemisphericus (Vaughan)[1]				x
Linoproductus spp.[1]			x	x
Megachonetes sp.(broad papilionaceous forms)[1]	x	x	x	
Martinia sp.[1]				x
Orthetetids[1]	x	x	x	x
Pliochonetes cf.crassistrius[1] (McCoy)	x			
Pustulids[1]	x	x	x	
Reticularia spp.[1]	x	x	x	x

	L.T.	U.T.	C_2S_1	S_2
Retzia (Hustedia) carbonaria (Davidson)[1]	x			
Rhipidomella michelini (Léveillé)[1]	x	x	x	
Rhynchonellids undet.[1]			x	
Rugosochonetes cf.hardrensis (Phillips)[1]	x	x	x	
Schellwienella crenistria (Phillips)[1]	x	x		
" sp.			x	
Schizophoria resupinata (Martin) and related forms[1]	x	x	x	x
Schuchertella cf.fascifera (Törnquist)		x		
" wexfordensis Smyth		x		
Spirifer cf.bisulcatus (Sowerby)[1]			x	
Spirifer cf.konincki (Dewalque)		x	x	
Spirifer tornacensis (de Koninck) Group	x	x		
Spiriferellina octoplicata (Sowerby)[1]		x		
" sp.[1]	x			
Syringothyris cuspidata (Martin)[1]	x	x	x	
" elongata (North)	x			
Tylothyris cf. laminosa (McCoy)[1]		x		

Footnote

1. Also recorded by Dixon and included in the Faunal list (1921 pp.74-82).

5. Faunal list for the Tenby Outcrop

The columns are named as follows:

T. Tournaisian Main Limestone comprising the *Zaphrentis* Zone and Lower *Syringothyris* subzone of Dixon (1921 pp.88-89)

C_2S_1 Upper *Syringothyris* and Lower *Seminula* subzones of Dixon (1921 pp.89-90)

S_2 Upper *Seminula* subzone of Dixon (1921 pp.90-91)

	T.	C_2S_1	S_2
(a) Rugose corals			
Caninia cornucopiae Michelin[1]	x		
Carcinophyllum spp.[1]		x	x
Lithostrotion martini Edward and Haime[1]		x	
" portlocki (McCoy)			x
Palaeosmilia murchisoni Edward and Haime[1]		x	
Rotiophyllum omaliusi Edward and Haime[1]	x		
Zaphrentoids undet.[1]	x		
(b) Tabulate corals			
Alveolites septosa (Fleming)[1]			x
Michelinia sp.[1]	x	x	
Syringopora cf.distans (Fischer de Wald)[1]			x
" cf.reticulata (Goldf.)[1]	x	x	
(c) Brachiopods			
Actinoconchus expansus (Phillips)[1]			x
Athyrids (undifferentiated)[1]		x	x
Camarotoechia mitcheldeanensis (Vaughan)[1]	x		
Cleiothyridinia roissyi (Léveillé)[1]	x		
Composita ficoides (Vaughan)[1]		x	x
Davidsonina carbonaria (McCoy)[1]			x
Daviesiella comoides (Sowerby)[1]		x	
Derbya bristollensis (Vaughan)[1]	x		
Dictyoclostus vaughani (Muir Wood)	x		
" spp.		x	x
Dielasma cf. hastata (Sowerby)[1]		x	
Gigantoproductus giganteus (Martin) Group[1]			x
Leptaena analoga (Phillips)[1]	x		
Linoproductus corrugato-hemisphericus (Vaughan)[1]			x
" hemisphericus (Sowerby)[1]			x

	T.	C_2S_1	S_2
Megachonetes sp. (broad papilionaceous forms)[1]	x		
Orthetetids undet.[1]	x	x	
Rugosochonetes cf.hardrensis (Phillips)[1]	x		
Rhipidomella michelini (Léveillé)[1]	x		
Schellwienella crenistria (Phillips)[1]	x	x	
Schizophoria resupinata (Martin) and related forms[1]	x	x	
Spirifer cf.bisulcatus (Sowerby)[1]	x	x	
" tornacensis (de Koninck) group	x		
" spp.[1]		x	
Syringothyris cuspidata (Martin)[1]		x	
Tylothyris cf.laminosa (McCoy)[1]	x		

Footnote

1. Also recorded by Dixon and included in the Faunal list (1921 pp.74-82)

6. Faunal list for the West Williamston Outcrop

The columns are named as follows:

T. Tournaisian Main Limestone comprising the *Zaphrentis* Zone and Lower *Syringothyris* subzone of Dixon (1914 pp.137-139)

C_2S_1 The Upper *Caninia* Zone comprising the lower part of the Upper *Syringothyris* subzone, Group 9 of Dixon (1914 p.139)

S_2 The *Seminula* Zone comprising the main part of the Upper *Syringothyris* subzone and *Seminula* Zone of Dixon (Groups 10,11 and 12, 1914 p.139-140)

	T.	C_2S_1	S_2
(a) Rugose corals			
Carcinophyllum spp.			x
Lithostrotion affine (Fleming)			x
Lithostrotion martini Edward and Haime			x
" pauciradiale (McCoy)			x
Zaphrentoides undet.	x		
(b) Tabulate corals			
Alveolites cf. septosa (Fleming)			x
Michelinia megastoma (Phillips)			x
Michelinia sp.	x		
Syringopora spp.			x
(c) Brachiopods			
Athyrids (undifferentiated)			x
Avonia bassa (Vaughan)	x		
Buxtonia scrabicula (Martin)	x		
Camarotoechia mitcheldeanensis (Vaughan)	x		
" cf.pleurodon (Phillips) var davreuxiana (de Koninck)			x
Cleiothyridina cf.glabristria (Phillips)			
" roissyi (Léveillé)			
Composita ficoides (Vaughan)			
Crancrinella undata (Defrance)			x
Davidsonina carbonaria (McCoy)			x
Daviesiella cf.comoides (Sowerby)	x		
Dictyoclostus vaughani (Muir Wood)	x		
" sp.			x
Dielasma sp.			x

	T.	C_2S_1	S_2
Gigantoproductus giganteus (Martin) Group[1]			x
Leptaena analoga (Phillips)[1]	x		
Linoproductus corrugato-hemisphericus (Vaughan)[1]			x
" hemisphericus (Sowerby)[1]			x
Megachonetes sp. (broad papilionaceus forms)[1]	x		x
Productus garwoodi (Muir Wood)[1]			x
Rhipidomella michelini (Léveillé)[1]	x		x
Rhynchonellids undet.[1]			x
Rugosochonetes cf. hardrensis (Phillips)[1]	x		
Schellwienella crenistria (Phillips)[1]	x		x
Spirifer tornacensis (de Koninck) Group	x		
" spp.[1]	x		x
Syringothyris cuspidata (Martin)[1]	x		x
" cuspidata mut. cyrtorhynchia (North)	x		
Tylothyris cf. laminosa (McCoy)[1]	x		

(d) <u>Gasteropods</u>

	T.	C_2S_1	S_2
Bellerophon spp.[1]			x

(e) <u>Lamellibranchs</u>

	T.	C_2S_1	S_2
Aviculopecten sp.			x
Minute lamellibranchs		x	

Footnote

1. Also recorded by Dixon (in Strahan & others 1914 p.143)

7. Faunal list for the North Crop of Pembrokeshire

The columns are named as follows:

T. The residual Tournaisian Main Limestone comprising the *Zaphrentis* Zone of Dixon (1914 p.131)

C_2S_1 The Upper *Caninia* Zone, comprising the "Pendine Conglomerate" of Dixon (1914 p.131)

S_2 The *Seminula* Zone comprising the Lower and Upper *Seminula* subzones of Dixon (1914 pp.130 and 133)

	T.	C_2S_1	S_2
(a) Rugose corals			
Caninia cylindrica (Scouler) group			x
Carcinophyllum spp.			x
Lithostrotion martini (Edward and Haime)			x
Zaphrentoids undet.	x		
(b) Tabulate corals			
Alveolites sp.	x		x
(c) Brachiopods			
Actinoconchus cf.planosulcatus (Phillips)			
Athyrids (undifferentiated)	x		x
Avonia bassa (Vaughan)	x		
Camarotoechia mitcheldeanensis (Vaughan)	x		
Cleiothyridinia roissyi (Léveillé)	x		
Composita ficoides (Vaughan)			x
Davidsonina carbonaria (McCoy)			x
Dictyoclostus vaughani (Muir Wood)	x		
Krotovia spinulosa (Sowerby)	x		
Leptaena analoga (Phillips)	x		
Linoproductus spp.			x
Orthetetids undet.	x		
Pustulids undet.	x		
Reticularia sp.	x		
Rhipidomella michelini (Léveillé)	x		
Rugosochonetes cf.hardrensis (Phillips)	x		
Schellwienella crenistria (Phillips)	x		
Schizophoria resupinata (Martin)	x		

	T.	C_2S_1	S_2
Spirifer tornacensis (de Koninck) group	x		
Spiriferellina octoplicata (Sowerby) and vars.	x		
Syringothyris cuspidata (Martin)	x		

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