THE PALAEOECOLOGY OF UPPER VISEAN MARINE
MUDSTONES, NEAR DUNBAR, EAST LOTHIAN

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ABSTRACT

The palaeoecology of the mudstones lying between the Skateraw Middle Limestone and the Skateraw Upper Limestone, near Dunbar, East Lothian, has been studied and because of its related origin consideration has also been given to the palaeoecology of the Skateraw Upper Limestone. These horizons are shown to lie at the position of the Neilson Shell Bed of the Central Coalfield of the Midland Valley of Scotland and are of Lower Limestone Group age (Late Viséan, P2).

Borehole evidence shows that both the mudstone and the Skateraw Upper Limestone vary considerably in thickness with an elongate axial zone of maximum thickness in the southern parts of the area considered. This is interpreted as a positive bank-like NW - SE trending feature which had a more steeply sloping north face and whose maximum palaeorelief was in the order of 20m.

The fauna of the mudstone has been investigated by the detailed extraction of macrofossils from a column, with a cross-sectional area of 0.9m², through the succession at each of three localities (Dunbar Works, Catcraig and Skateraw). This has been supplemented by extensive field collections from the mudstone and Skateraw Upper Limestone.

The distribution, palaeoecology and taphonomy of each of the species in the highly diverse fauna is discussed. Azimuthal orientations reveal the presence of currents flowing from the south / south west and east /
south east and way-up orientations show that the environmental energy was least on the bank (Dunbar Works) and greater immediately to the north of the bank (Skateraw). Particular attention has been paid to two species - *Eomarginifera longispina* (J. Sowerby) and *Zeacrinites konincki* Bather - in relation to their occurrence at other Scottish localities. The preservation of the productid, *E. longispina*, is shown to be related to changes in shell structure and character with age coupled with its life history which involves a juvenile attached phase, a possibly free swimming adolescent phase and a sessile epifaunal adult phase. *Z. konincki* is shown to have had very high juvenile and gerontic mortality rates. Variation in the CD-interradius of this crinoid is separated into ontogenetic and genetic components. Temporal and spatial changes in the genetic component are related to evolutionary effects.

An association analysis of the detailed collections reveals the presence of eight biofacies whose fauna is interpreted as having been controlled by various combinations of turbidity and environmental energy. The predominance of filter feeding organisms is related to the availability of an abundant food supply. Minor amounts of transport of the bank faunas north into the off bank areas are recognised.

The patterns of lithological and biofacies changes in the mudstone and Skateraw Upper Limestone successions are related to the interaction of the two current systems and to the availability and supply of detrital muds. There is an over all trend to clearer water conditions
but the history of the bank is abruptly terminated by a rapid influx of deltaic sediments. Deposition occurred in tropical to subtropical marine waters at depths of 35 to 70m.

The echinoid *Lepidesthes caledonica* Jackson is redescribed and four other new species - a hybrid, an echinoid (*Lepidesthes cloughi* sp. nov.) and two dendroid graptolites (†*Ptiograptus dambarense* sp. nov. and dendroid sp. indet) - are described.
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I - INTRODUCTION

IA) Aims and Procedures

The aim of this thesis has been to study the lateral and vertical variation in the fossil macrofauna of a mudstone horizon and to relate this to the depositional environment. For this purpose a mudstone exposed in the Dunbar, East Lothian area was chosen as it was readily accessible, fossiliferous and known to be exposed at three localities.

The topic has been developed along the lines indicated in the flow diagram (fig 1). General field mapping and a close study of the succession were carried out to ensure that the three exposures were at the same horizon (an obvious prerequisite for a valid study) and to place the studied horizon in a stratigraphic context. Considerable use has been made of borehole data which were kindly supplied by Associated Portland Cement Manufacturers Limited.

The mudstone has been studied by extraction of more or less complete sections from each locality and the macrofauna of these has been collected in the laboratory after the rock has been subjected to a softening process. To assist in the identification of fossils supplementary hand specimens were collected from each locality. The mudstone and the overlying limestone are believed to have a close genetic relationship and the fauna of this has also been considered.
The results of the two approaches - stratigraphical and palaeontological - have been synthesised and an environmental interpretation made.

IB) Horizon and Location

The horizon selected for study outcrops in the northern part of a small Carboniferous outlier to the south of Dunbar, East Lothian (O.S. 1 inch sheet 63; G.S. 1 inch sheet 33). The band is a mudstone and lies between two limestones (the Skateraw Middle Limestone and the Skateraw Upper Limestone) of Lower Limestone Series (Upper Visean, P₂) age (Clough et al 1910; Currie 1955). Fuller details of the geology are given below (section II).

The mudstone was intensively collected from, at three localities within the area

a) Skateraw (NT 739755) on the lower shore near low water mark at a point 50m due east of the remains of Skateraw Harbour (fig 2, 3). The site is 46°E of the West Kiln and 270°E of the East Kiln.

b) Catcraig (NT 719771) on the upper shore in front of Barns Ness Caravan Site. The locality is 55m 340°E of the concrete plinth which marks the outcrop of the Skateraw Upper Limestone (No 6) for the local Geology Trail (Tindall et al 1969) and is 272°E of the Barnsness Lighthouse (fig 2, 4).
c) Dunbar Works (NT 711761) on the north wall of the quarry at a point 100 m 145°E of the railway bridge (near entrance to the quarry). This site while still visible is no longer accessible due to quarrying operations (fig 2, 5).

IC) Methods

IC1 Collection of Columns

Vertical sections of the mudstone were removed, in successive slabs, from each of the three localities. At two of the localities, Skateraw and Dunbar Works, free vertical faces of the mudstone were exposed and these could be relatively easily exploited after weathered material had been removed. At Catcraig no suitable free face was exposed and a column was created by excavating down from the upper surface of the bed and isolating a central pillar. The columns were extracted with a view to using an area measuring 0.3m by 0.3m for each layer but due to the uncertainties of how well each piece would extract and transport a generous margin of error was allowed. Pieces of this excess material have been retained for future microfossil studies and other pieces were used for microscopic study of lithology. Before any piece of rock was removed it was inscribed on its upper surface with the direction of magnetic north and with a serial number. The number was also clearly written in waterproof ink on the newspaper in which each piece was wrapped.

IC2 Supplementary Collections

Supplementary collections of fossil material were made at each locality. These are primarily to assist in the identification of the
specimens found in the column material but have also yielded considerable information for biometric and other studies.

The Skateraw Upper Limestone is poorly fossiliferous except at Dunbar Works where there is an abundant and varied fauna. Unfortunately this cannot be collected in situ but a fossil list has been drawn up based on material collected from a spoil heap of this limestone created during quarrying operations.

1C3 Examination of Columns

In the laboratory the column material from each locality was reassembled in blocks and trimmed (using a masonry saw or hacksaw) to a suitable size for treatment. The cross-sectioned (i.e. 'bedding plane') area used was 0.09m² and though most blocks were square some rectangular shaped blocks (e.g. 0.2m by 0.15m) were also used. The thickness of the individual blocks into which each column was subdivided varied from 20mm up to a maximum of 220 mm. Each block was then subjected to a softening process (see section 1Ch) and the macrofauna collected. The fossils in each 20mm layer were recorded together. Each fossil was identified as far as possible and where relevant various other features indicating its status (e.g. shell, valve, fragment etc.); orientation (with respect to north and to the bedding), size and relation to other fossils (e.g. juxtaposition of fragments, encrusting etc.) were noted.

Pieces of the excess material have been retained and some of
these have been used for preparation of thin sections to allow a study of the lithology.

**II. Softening Processes**

Two softening processes have been used during the course of the study. The first of these, the Paraffin-Water technique, is a slight adaption of the method pioneered by Ferguson (1960). With this method softening occurs when a paraffin soaked block of mudstone is immersed in water. Ferguson (1960) found that the Second Abden Shale material required to be dried and treated a second time but in the present study only one treatment was required. Experience with a variety of shales suggests that if a rock does not show a marked reaction on the first treatment it is unlikely to react further on recycling. In all cases the rock was air dried though Ferguson (1960) oven dried his shales.

The time required for immersion in paraffin is critical only in that the material must be completely penetrated by the paraffin. Long periods (e.g. several weeks) of immersion did not seem to enhance the process and in practice a period of three to four days was normally allowed, though this probably allows a generous safety margin. The soaking in paraffin does not appear to materially weaken the shale but when the paraffin soaked block is immersed in water then disintegration may occur. In the case of the Dunbar material disintegration proceeds, as long as the block is left immersed in water, until the whole fabric of the rock has been destroyed. The process can be halted at intermediate stages by draining off the water and it is thus possible to obtain softened blocks whose fabric is undisturbed. Unfortunately a precise
control cannot be established since the by now water soaked block continues to disintegrate slightly even after the water has been drained off. As the mudstone disintegrates very rapidly the material never needed to be immersed in water for more than one hour and often had to be drained after as little as ten to fifteen minutes.

The size of the block is another important factor due to the time lag in the onset of disintegration as the water penetrates the block. This could have two possible consequences. Firstly if the rate of penetration were slow relative to the rate of disintegration then it would be necessary to halt the process before the central parts of the block had been penetrated. In the present study this was partly offset by the fact that most 'blocks' used were compounded from several smaller slabs which thus increased the effective rate of penetration. Nevertheless in all blocks a slight loss of material occurred due to fraying of material on the sides of the block and in many of the blocks subsequent working revealed a faint internal 'onion-skin' structure suggesting that though disintegration had been satisfactory penetration had not been uniform. The second possible consequence relates to the fact that one of the penetration fronts moves inwards and upwards from the base, thus creating a soft layer at the base, which if the superincumbent weight is great might be compacted and even squeezed out. Such a situation was thought to have occurred in one very large trial run but there was no evidence (e.g. loss of thickness, disturbed bedding, autointrusion along cracks) that this ever occurred to a marked degree with any of the column blocks. Due to the above possibilities an alternative process (see below) has been used on the mudstone material from Dunbar works which in
trial runs always reacted with extreme rapidity to the paraffin water technique.

The underlying mechanism of the paraffin-water process whether physical or chemical is unknown and as previously indicated different rocks show varied reactions. In extreme cases total disintegration occurs and the clean fossils can be washed out of the resultant sludge while at the other end of the scale some shales show no reaction or at best only a slight enhancement of the fissility. The best results seemed to be obtained on non calcareous shales with high contents of pyrites and organic material. Such material when softened becomes much lighter in colour.

As mentioned above an alternative method was used for preparing the Dunbar Works column material. While in the field it had been observed that at Dunbar Works the fresh mudstone slabs which were extremely hard and non-fissile soon disintegrated to heaps of small mudstone fragments if they were exposed to the alternate wetting and drying of the British summer. This feature which had caused some concern during the collection of the mudstone was utilised and simulated in the laboratory by immersing the reassembled blocks in water and then allowing them to dry. The process was repeated once or twice.
IIA) Introduction

The area has the distinction to be the first part of Scotland to have been mapped by the Geological Survey (Ramsay 1866; Geikie 1895 p 219; Flett 1937 p 60) and it is the publications of this institution which provide the major source of information about the area. The original survey, started by A. C. Ramsay in 1854, was completed by H. H. Howell and A. Geikie and the results were incorporated in a map (Geological Survey 1 inch sheet 33-1860) and a memoir (Howell et al 1866). The area was remapped between 1902 and 1905 by C. T. Clough and a map (Geological Survey 1 inch sheet 33-1905) and a memoir (Clough et al 1910) were issued. Information from this revision was incorporated in a paper by Crampton (1905) and most of the subsequent Geological Survey publications which mention the area are also based on Clough's work though some do introduce previously unpublished information (Haldane et al 1943; Carter 1966). A second revision has been completed (Stubblefield 1962, 1963, 1964, 1965; Dunham 1968) but the results have not yet been published.

The coastal sections within the area have long been popular with geologists and as a result there are several publications which mention features of the area (see bibliography in Clough et al 1910 p 218 - 220) but the only other work to deal with the area as a whole is that of Wilson (1952) whose results are in agreement with those of Clough et al (1910).
The popularity of the coast is also reflected in the existence of several guides to the Catcraig and Barns Ness shore section (Craig 1960; Davies and Greig 1971), which has recently been laid out as a geological trail (Tindall 1969).

The results of the field work undertaken in the present study confirm the general succession established by Clough et al. (1910) and by Wilson (1952) and also confirm their implicit correlation of horizons between the Catcraig - Barns Ness, Skateraw - Longcraig and Dunbar Works (Oxwell Mains) sections. However as stressed above (section IA) a valid correlation is fundamental to this study and the successions and their correlation are therefore described below (section IIB). The three successions are illustrated in figure 6.

IIB) Stratigraphic Succession

IIB1) Strata below the Longcraig Middle Limestone

Strata underlying the Longcraig Middle Limestone are only exposed in the Catcraig and Longcraig sections and are of little importance to correlation within the area. At Catcraig a massive sandstone post (1 m) is seen to pass down into thin bedded silty sandstones of which 0.5 m are exposed. The upper surface of the sandstone contains small calcareous nodules and abundant canda galli markings (Zoophycos sp.). At Longcraig 7 m of sandstone and siltstone are underlain by a limestone the top 3.5 m of which are visible. This limestone - the Longcraig Lower Limestone - is cream to buff in colour and is very nodular with shale partings and
and bands. Fossil debris including brachiopod (spiriferoid and productoid) species, crinoid and bryozoan material is common in the limestone.

Boreholes at Carcraig (Clough et al 1910 p 136; APCM Ltd) have proved 5.5m of limestone at this position.

IIB2 The Longcraig Middle Limestone and associated strata

The Longcraig Middle Limestone and the strata lying between it and the Longcraig Upper Limestone are extremely important in the correlation of the Catcraig - Barns Ness and Skateraw - Longcraig successions but are not exposed in the Dunbar Works succession. At Longcraig the limestone which rests directly on the underlying sandstones is very nodular and shaly at the base where it varies from light grey to cream in colour and contains crinoid debris, cups of Ureocrinus bockschii, spines of Archaeocidaris sp., Dielasma hastata, Rhipidomella michelini, Composita ambigua, Productus (Avonia) cf. davidsoni, Avonia youngiana and a trilobite sp. The top of the limestone is more massive, more uniformly cream in colour and contains Lithostrotion spp. The upper surface of the limestone is extremely uneven and as a result the thickness of the limestone varies from 0.8m to 1.7m. A creamy grey ganister and a thin (70mm) coal seam lie between this limestone and the Longcraig Upper Limestone. The ganister varies from 0.6m to 1.2m in thickness and fills in and even cut the irregularities in the upper surface of the limestone.

At Catcraig the lower nodular beds are similar to those at Longcraig and contain the same fauna (with the exception of trilobites and the
addition of _Hydreionocrinus_ sp.). The upper more massive beds are almost entirely composed of _Lithostrotion_ spp. and contain solitary corals and nests of productoids. The upper surface of the limestone is extremely well displayed and it can be seen that the irregularities are due to closely packed basin shaped hollows which may measure up to 1m in diameter and 0.5m in depth. The upper surface contains large numbers of more or less vertical cylindrical ironstone nodules and in places has a brecciated appearance. The ganister is rich in carbonaceous streaks and contains _Stigmaria ficoides_, some of which pass down into the underlying limestone. The coal is 100m thick.

Whether the basing of the limestone is due to penecontemporaneous erosion (Hemmingway 1968 p. 50) or to solution during formation of the overlying regolith (similar to that described by Larsen and Chilingar 1967) is uncertain but it is believed that uplift has occurred and that the creamy colour of the limestone is the result of penecontemporaneous leaching by humic acid. This horizon of subaerial weathering is extremely important not only for correlation within the area but also for correlation with other areas (see section IID).

IIB3 The Longcraig Upper Limestone

The Longcraig Upper Limestone is exposed at Longcraig and forms the base of the Dunbar Works succession (fig 6). The limestone, which has a basal calcareous shale (0.7m), consists of a series of grey limestone posts which contain small particles of crinoid and other fossil debris and occasional small colonies of _Lithostrotion_ sp. The posts are separated by thin
unfossiliferous shale partings and have undulating bedding surfaces. This limestone has been penetrated by a large number of the APCM Ltd. boreholes and varies in thickness from 6.5m to 9.0m (average 7.7m). Two bands in the limestone, the basal shale and a coral band near the top, are particularly useful in the correlation of the successions.

The shale is exposed at Catcraig and at Longcraig and at both localities can be subdivided into three portions. The base (160mm) is silty and apart from a few thin shelled bivalves found at Catcraig is unfossiliferous. This is overlain by a layer (120mm) which is rich in Schizophoria resupinata and Streblopteria onata and which also contains large (up to 30mm diameter) pedicle valves of Orbiculoidea sp. The upper portion (430mm) contains abundant Eomarginifera longispina and grades up into the lowest limestone post.

The coral band, known locally as the Dunbar Marble, is exposed at all three localities and lies about 1.0m below the top of the limestone. The band is almost entirely composed of Koninokophyllum echinatum and other solitary corals though occasional colonies of Lithostration sp. also occur. The band varies in thickness from 0.7m to 0.2m and at Catcraig it appears to be absent in places. At Longcraig it appears to have formed by the coalescence and overlap of several distinct lenticular accumulations of coralla.

At Dunbar Works the limestone is capped by a layer (60mm) of ironstone which contains a sparse fauna of bryozoa, productids, bellerophontid gastropods, Wilkingia sp., Conularia sp., fish teeth and
plant fragments. The bivalve, *Wilkingia* sp., is the most common element and is often found in its life position. The top of the limestone is not exposed at Longcraig and a careful search at Catcraig has shown that this band is absent there though the upper surface of the limestone has a ferruginous stain.

**III:** Strata between the Longcraig Upper Limestone and the Skateraw Lower Limestone

The elastics which lie between the Longcraig Upper Limestone and the Skateraw Lower Limestone are best exposed in the Dunbar Works succession where they have a total thickness of 7.4m. The lowest beds are silty mudstones (1.8m) which contain occasional specimens of orthocenes, *Conularia* sp. and pectenid bivalves in the basal metre. These are overlain by a series of rapidly alternating sandstones, siltstones and shales which are ripple marked and extensively bioturbated and which are capped by a massive sandstone post (1m). The sandstone contains wide (35m), shallow cut and fill structures and is separated from the Skateraw Lower Limestone by a thin (30mm maximum) coal seam.

At Longcraig only the upper 5m of these beds are exposed and closely resemble the upper sandy beds of Dunbar Works. The full sequence is exposed at Catcraig where it is flatlying and the ripple marks, trails and other trace fossils are extremely well displayed. These strata vary from 4.9m to 7.5m in thickness (average = 7.0m) in the APCM Ltd. boreholes.
The strata between the Skateraw Lower and Middle Limestones are very similar in both character and thickness at Skateraw (3.7m) and at Catoraig (3.8m). A basal silty mudstone (2.2 - 2.5m) with large ironstone concretions passes up into a silty sandstone (0.8 - 1.0m) containing irregular rootlike and sheety ironstone nodules. The upper surface of this sandstone is particularly rich in ironstone nodules and has an irregular polygonal patterning (?suncracks). This is overlain by a soft grey fireclay (0.5m) which contains abundant *Stigmaria ficoides* and on which lies a thin (200mm) seam of coal.

At Dunbar Works the succession is thicker (4.1m) and slightly different in character. The basal mudstone (3.2m) passes sharply up into a fine grained sandstone (1.2m). The base of the sandstone is cross bedded and contains small ironstone nodules and small cubes of pyrites. The upper parts of the sandstone are unbedded and contain *Stigmaria ficoides*. The overlying coal is 250mm thick.

A slight variation on this succession was exposed near the north end of the Dunbar Works quarry during quarrying operations in the summer of 1969. At this time a green pyritic mudstone (50mm) was observed to be intercalated within the sandstone bed. This mudstone and the underlying cross bedded sandstone (0.5m) were deeply (100mm) sun cracked. These cracks had been infilled by the overlying sandstone (0.7m) which contained *Stigmaria ficoides*. Small rootlets extended from the *Stigmaria* down into
the lower sandstone and disturbed the cross bedding.

IIB7 The Skateraw Middle Limestone

As it lies immediately below the studied horizon the Skateraw Middle Limestone is extremely important in the correlation of the three successions. The limestone, whose thickness varies from 3.7m to 5.7m (average 5.0m) is composed of a series of limestone posts separated by thin shale partings. The character and sequence of the posts is almost identical in the three successions (table 1) and the most distinctive beds are the basal shale (bed q), the upper surface of bed o, the Saccaminopsis band (bed b) and the echinoid band (bed a).

__Chaetetes__ colonies which are common in the lower parts of the limestone occur in two forms - small bun shaped colonies and flat disc shaped colonies. The flat colonies invariably rest on a lensoid accumulation of fossil material. This fossil debris, which consists of crinoid columnals with some productid and coral fragments, is often irregularly encrusted by algae. It has not been possible to determine whether these fossil accumulations are the protected remnants of more extensive layers or whether they are small localised developments utilised by the corals. The orientation distribution of columnals in these lenses may be markedly different from that of columnals in the surrounding limestone (fig 8e, f). Orientation distributions however also vary considerably at different sites on a single bedding plane (fig 8b, c, d, e). The distributions are interpreted as resulting from current action with an E-W or E.S.E. - W.S.W. direction but 'T' and 'V' shaped patterns (Schwarzacher 1963) are ambiguous.
as to the actual current direction. The concave-up gigantoproductid shells which occur on the upper surface of bed o at Skateraw show no marked preferred orientation direction but of 17 specimens whose umbonal direction has been measured 15 have azimuths lying in the 210° sector between 170°E and 20°E. This may indicate a diffuse life orientation to an easterly current.

A stratum contour map for the top of the limestone is illustrated in fig 7.

IIB8 The Mudstone and Skateraw Upper Limestone

This group of strata consisting of the studied horizon and the overlying Skateraw Upper Limestone whose palaeoecology is also considered shows both thickness and facies variations (see section III).

At all three localities the mudstone is separated from the Skateraw Middle Limestone by a thin breccia zone consisting of mudstone and limestone fragments set in a soft red clay matrix. This is believed to be genetically related to thrusting and other structural features of the area (see section IIC).

At Skateraw the breccia (20mm) is overlain by 300mm of calcareous shale which passes up into mudstone (600mm). The Skateraw Upper Limestone consists of a lower leaf of calcareous nodular ironstone (80mm) and an upper leaf of dark crinoidal limestone (310mm) separated by a shale band (70mm). The Catcraig sequence is similar to that at Skateraw in both
character and thickness (breccia 25mm, shale 300mm, mudstone 700mm, ironstone 120mm, shale 20mm, limestone 340mm).

At Dunbar Works the succession is variable in thickness and reaches its maximum thickness close to the collection site. Here the basal breccia is 150mm thick and is overlain by 4.0m of dark mudstone. The lower parts of the Skateraw Upper Limestone are siderite rich fossiliferous limestones (1m) which become shaly towards the top and are separated from an upper coralline band by a massive post of crinoidal limestone (0.5m). The coralline band is composed almost entirely of Lithostrotion junceum and is 0.8m thick.

IIB9 Strata between the Skateraw Upper Limestone and the Chapel Point Limestone

The sequence of sandstones, siltstones and shales which lies between the Skateraw Upper Limestone and the Chapel Point Limestone is not well exposed in the area and at Dunbar Works only the basal 3m are present. These consist of dark silty mudstones which contain pyritic burrow traces and which have, at the base, yielded a sparse marine fauna of Saphrentis delanoci, Microcyathus cyclostomus, Eomarginifera Longispina Nuculopsis gibbosa, 'Dentalium' sp, Rugosochonetes speciousus. Crinoid columnals are rare and when found appear to have been bored and abraded.

At Skateraw a similar fauna, containing in addition bellerophontid gastropods, Straparollus (Eumphalus) carbonarius and Polidercia attenuata occurs in the mudstones overlying the Skateraw Upper Limestone. These
mudstones are not fully exposed but appear to be about 11m thick and to pass upwards into a sequence of well bedded sandstones and siltstones (20m). Spirifer ?trigonalis and crinoid columnals have been found in a sandstone 4.5m above the base of these sandy beds. This band appears to have been first recognised by Wilson (1952). The sandstones become thicker and more predominant towards the top of the sequence and are often cross bedded. One bedded sandstone passes laterally into a bed with highly convoluted laminations. The upper-most bed to be exposed is an intensely bioturbated ganister containing long lengths of Stigmaria ficoides. The thickness of the unexposed strata which lie between the ganister and the Chapel Point Limestone is very small (c.0.6m).

The sequence at Catoraig is also estimated to be about 30m thick but is very poorly exposed especially at the base. A zaphrentid coral and a few crinoid ossicles have been found immediately above the Skateraw Upper Limestone where up to 1m of mudstone is occasionally exposed. The upper beds appear siltier than their equivalents at Skateraw and the Chapel Point Limestone rests directly on the ganister. The equivalent of the bed with Spirifer has not been located but appears to have been recognised by Davies and Greig (1971).

The Chapel Point Limestone which is 2.6 to 2.9m thick occurs in both the Skateraw and Catoraig successions and is the highest bed considered in the correlation of the successions. This limestone is
light grey in colour weathering brown and has sandy crinoidal base features of which have been described by Cain (1968). Crinoid debris and Zoophycos sp. are common throughout the limestone but other fossil material is scarce. Small colonies of Lithostrotron sp. occur on some of the lower bedding planes and towards the top a few large bell-erophontid gastropods have been found. Large chert nodules, which contain sponge spicules and other small fossil particles (Clough et al 1910 p 137), occur in the middle of the bed. At Catcraig the upper surface of the limestone is rich in Spirifer trigonalis and spines of Archaeocidaris sp.

12 to 13 m of strata occur above the Chapel Point Limestone at both Catcraig and Skateraw but the successions are too poorly exposed to be of assistance in establishing a correlation between the two localities. The two sequences are dominated by fine to coarse sandstones and a sandy limestone, the Barness East Limestone, containing crinoid debris and Zoophycos sp. occurs near the top of both successions. In the Skateraw succession a similar limestone, the Dryburn Foot Limestone, occurs lower down in the sequence 3 m above the Chapel Point Limestone.

IIIC) Structure

The rocks of the area generally dip towards the north east (fig 2, 7) and the easterly component of this dip may be partly due to drag associated with movement on the Dunbar-Innerwick fault. This fault which forms part of the western boundary of the area is a large reverse
fault (Wilson 1952) and brings the Carboniferous rocks of the area into contact with sandstones and conglomerates of Lower Old Red Sandstone age. The regional dip is highly disturbed in the north of the area where round Catcraig a complex anticlinal structure has developed. A second less marked disturbance is caused by the east facing monoclinal flexure lying to the south of Catcraig and to the east of Dunbar Works.

The faults of the area are aligned in an E - W or NE - SW direction and downthrow to the north. Wilson (1952a) has suggested that there may also be left lateral horizontal component of movement on the E - W faults and the disposition of the thin quartz dolerite dykes at Catcraig, which might be the faulted expression of a single intrusive sheet, suggests that there may have been right lateral movement on the NE - SW faults. Fault planes, especially where they intersect limestones, are often marked by zones of brecciation which may be up to 1m wide. The breccias are usually cemented by calcite veins but in one of the Catcraig quarries the breccia has been replaced by an extensive development of iron oxides (Clough et al 1910 p 167). Zinc blende, galena, pyrites and barytes crystals have also been found in the calcite veins.

In addition to the major structures a large number of minor fold and thrust structures with a NNW strike have been observed. These structures are only found in the limestones and in the thicker limestones, such as the Skateraw Middle Limestone, open folds in the upper parts are often accompanied by thrusting in the lower parts. Thrust planes dip both east and west at 10° to 20° and in addition to slickensided calcite
crystals may also contain occasional crystals of zinc blende, galena, pyrites and barytes. The deformation of the limestones is accommodated in the adjacent competent shales by small scale thrusting and the brecciation between the Skateraw Middle Limestone and the mudstone is probably a similar effect. The style of these minor structures is very similar to that of structures developed in limestones in Northumberland (Shields 1964). Wilson (1952) has shown that the orientation of joints shows slight concentrations in NE - SW and NNW - SSE planes.

The structure of the area, as suggested by Wilson (1952) probably results from an ENE - WSW compression which may be of Armorican age.

IIID) Regional Correlations

IIID1 Introduction

The strata of the area belong to the Lower Limestone Group and Calciferous Sandstone Measures of the Scottish Carboniferous Succession (Macgregor 1960). Such work as has been done on the depositional history of those groups has produced a complicated picture of basins and positive areas within the Midland Valley (Richey 1937; Goodlet 1957; Greensmith 1961, 1962, 1965). No objective studies have been carried out but it is generally inferred that sedimentation was cyclic (Goodlet 1959; Francis 1965; Duff et al 1967). Successions thus show considerable lateral and vertical variation and the detailed correlation of these groups is still a controversial subject. Correlations based on the comparison of sequences depend on the use of distinctive beds such as limestones and
coals as indices and it is clear that more detailed studies of successions will lead to better understanding of the depositional environments and ultimately to more refined correlations. Unfortunately knowledge of the succession is based mainly on surface exposures many of which are no longer visible or are in poor condition and it is only recently that detailed borehole studies have been made (Forsyth and Wilson 1965; Forsyth and Chisholm 1968; Forsyth 1970).

The limestones of the Dunbar succession are here correlated with horizons in Fife, Midlothian and N. England and the correlation with the Central Coalfield, and the Glasgow area in particular, is also discussed since this area contains the name locality for several of the important horizons of the Lower Limestone Group and Calciferous Sandstone Measures succession. The correlations are summarised in table 2.

IID2 Barness East Limestone

This limestone is correlated with the 'Hosie' Limestone of St. Monance (Kirkby's bed 2 - Geikie 1902) which is a similar sandy crinoidal limestone rich in Zoophycos markings. This bed is believed to be the equivalent of the Mid Kinniny Limestone of West Fife (Forsyth and Chisholm 1968) and hence the equivalent of the Carriden No 2 Limestone of West Lothian and the second Hosie Limestone of the Central Coalfield (Forsyth 1970). The Mid Kinniny Limestone has also been correlated with the Bilston Burn Limestone of Midlothian (Tulloch and Walton 1956). The equivalent horizon in the Berwick on Tweed area of North England is tentatively suggested to be the thin encrinital limestone which occurs
between the Dryburn and Sandbanks Limestone (Fowler 1926).

Clough et al (1910) suggested that the strata above the Barness East Limestone might be of Limestone Coal Group age thus implying a correlation of the Barness East Limestone with the Top Hosie Limestone. It is however believed that the top of the Lower Limestone Group is not exposed in the area though it may be exposed on the coast about one mile to the north of the area where the Top Hosie Limestone may be represented by a sandy crinoidal limestone which occurs 10m above the Barness East Limestone.

IID3 Dryburn Foot Limestone

The correlative horizon in the St. Monance succession is believed to be an unnamed marine band (Kirkby bed 14 - Geike 1902) which lies about 23m below the 'Hosie' Limestone. This bed has been correlated with the Lower Kinniny Limestone of W. Fife (Forsyth and Chisholm 1968; Forsyth 1970) and the Carriden No 3 Limestone of West Lothian (Forsyth 1970). It is suggested that this horizon can also be correlated with the Mid Hosie Limestone of the Central Coalfield (Macgregor et al 1925; Forsyth & Wilson 1965) and the Upper Vexhim Limestone of the Midlothian Coalfield (Tulloch and Walton 1958) but no equivalent can be recognised in the Berwick on Tweed succession (Fowler 1926).

IID4 Chapel Point Limestone

This limestone is correlated with a thick zone of marine shales (Kirkby bed 19 - Geikie 1902) in the St. Monance succession which are
believed to be the local development of the Seafield Marine Band of Central Fife (Forsyth and Chisholm 1968; Francis et al 1961). The marine band also occurs in West Fife (Forsyth 1970) and has been correlated with the Carriden No 4 Limestone of West Lothian. It is suggested that the following horizons are also correlatives of this level - the Main Hoste Limestone of the Central Coalfield (Forsyth and Wilson 1965; Macgregor et al 1925), the Lower Wexham Limestone of the Midlothian Coalfield (Tulloch and Walton 1958) and the Sandbanks Limestone of the Berwick on Tweed area (Fowler 1926).

IID5 Spirifer band

The small marine band found 16m below the Chapel Point Limestone is correlated with a thin marine cementstone band (Kirkby bed 27 - Geikie 1902; Wright 1914) in the St. Monance succession. The correlative horizon in West Fife is called the Mill Hill Marine Band (Forsyth and Chisholm 1968, Forsyth 1970) and may be equivalent to the Milngavie Marine Band of the Central Coalfield (Forsyth and Wilson 1925; Dinham and Haldane 1932), and the Carriden No 4A Limestone of West Lothian (Forsyth 1970; Macgregor and Haldane 1933). The bed is not developed in Central Fife (Forsyth 1970) and appears also to be absent in the Midlothian Coalfield. A shaly limestone with marine fossils which lies 8m below the Sandbanks Limestone probably marks the position of this horizon in the Berwick-on-Tweed area (Fowler 1926).
The Skateraw Middle and Upper Limestone

The correlation, first suggested by Crampton (1905; Clough et al. 1910), of the Skateraw Middle Limestone with the Five Foot Limestone of St. Monance is here accepted. The two limestones differ in thickness but occupy similar positions relative to lower correlated horizons (see sections IID7 - 9) and are both overlain by thick shale sequences. The Skateraw Upper Limestone is not represented in the St. Monance sequence and both it and the underlying mudstone are probably equivalent to part or all of the fossiliferous shales which overlie the Five Foot Limestone (Kirkby bed 34 - Geikie 1902).

The shales above the Five Foot Limestone have been identified, on the basis of their fauna, as the local representative of the Neilson Shell Bed (Wilson 1966). Wilson (1966) has shown that this bed can be traced across Fife, West Lothian and the Central Coalfield and as a result the Skateraw Middle and Five Foot Limestones can be correlated with the following limestones - Blackhall of Glasgow, Paisley and Campsie, Foul Hosie of South Lanarkshire, Fankerton of Stirlingshire, Carriden No 5 of West Lothian, Charlestown Main of West Fife and Woodhaven of Elie, East Fife. At none of the localities considered by Wilson (1966) do limestone bands appear within or over the Neilson Shell Bed but in West Fife at Invertiel and Seafield Tower (Francis et al. 1961; Wright 1912) limestone bands occur in fossiliferous shale sequences overlying the Charlestown Main Limestone.

Crampton (1905; Clough et al. 1910) applied the term Skateraw Middle Limestone to a limestone exposed at Aberlady, East Lothian and this
correlation is also accepted here. The Aberlady limestone is a grey compact limestone like the Skateraw Middle Limestone, is similar in thickness (Clough et al. 1910) and occupies the same position as the Skateraw Middle Limestone relative to lower correlated horizons (see sections IID7 - 9). Higher strata are not now exposed at Aberlady but a thin limestone (‘= Skateraw Upper Limestone) was formerly exposed a short distance above the limestone. Tulloch and Walton (1958) have correlated the North Greens Limestone of the Midlothian Coalfield with the Aberlady Limestone and also with the Charlestown Main Limestone.

The North Greens Limestone is an extremely thick limestone and generally consists of an upper sequence of well bedded argillaceous limestones (8 - 30m), a middle unit of dark pyritic shale (up to 1m) and a lower unit of grey compact limestones with irregular bedding planes (3 - 1m) (Tulloch and Walton 1958; Clough et al. 1910). The lower unit is very similar to the Skateraw Middle Limestone and can probably be correlated with it. The middle shale unit is believed to be equivalent to the mudstone at Dunbar and the upper limestones are probably represented at Dunbar by the Skateraw Upper Limestone and part at least of the overlying argillaceous sequence.

The Skateraw Middle Limestone has long been thought to be equivalent to the Acre Limestone of North England (Gunn 1898; Clough et al. 1910) and examination of sections in the Berwick on Tweed area has confirmed this correlation. On Holy Island the Acre Limestone is well displayed and can be seen to be a grey compact limestone with crinoid and other fossil debris. The sequence of posts within the Acre
Limestone is very similar to that in the Skateraw Middle Limestone with even bedded limestone posts near the base and a thick nodular post in the upper half. The Skateraw Upper Limestone is not represented in the Holy Island successions but at Ancroftsteads Limeworks fragments of a limy crinoidal ironstone similar to the lower part of the Skateraw Upper Limestone were found and appeared to be derived from a level about 1m above the Acre Limestone.

**IIID7 Skateraw Lower Limestone**

The Skateraw Lower Limestone was correlated by Crampton (1905; Clough et al 1910) with the St. Monance Little Limestone (Kirkby bed 49 - Geikie 1902) and with a thin limestone in the Aberlady succession. Both these limestones are thin (0.6 - 1.0m) and like the Skateraw Lower Limestone contain gigantoproducants and compound corals.

The St. Monance Little Limestone is believed to be the equivalent of the Charlestown Green Limestone of West Fife (Forsyth and Chisholm 1968; Forsyth 1970) and the Craighenhill Limestone of West Lothian (Forsyth 1970). Two limestones are believed to lie at about this level in the Central Coalfield (Forsyth and Wilson 1965) and the Skateraw Lower Limestone horizon is correlated with the upper of these - the Shields Bed of Campsie (Macgregor et al 1925; Forsyth and Wilson 1965). The Shields Bed dies out towards the south-west of the Central Coalfield while the lower horizon, the Inchinnan Limestone, only occurs in the south-west of the coalfield (Forsyth and Wilson 1965).
The correlative horizon in the Midlothian coalfield is believed to be the Dryden Limestone. This thin limestone is also impersistent and is only locally present on the east side of the Midlothian basin (Tulloch and Walton 1958). In the Berwick on Tweed area the equivalent horizon is probably an unnamed limestone lying between the Acre and Eelwell Limestones (Fowler 1926).

IID8 Longcraig Upper Limestone

This thick limestone closely resembles the St. Monance Brecciated Limestone (Kirkby bed 53 - Geikie 1902) and a thick dolomitic limestone at Aberlady with both of which it has been correlated (Crampton 1905; Clough et al 1910).

The St. Monance Brecciated Limestone has recently been shown to be a major marine limestone in East Fife (Forsyth and Chisholm 1968) and has been correlated with the Charlestown Station Limestone of West Fife (Forsyth and Chisholm 1968; Forsyth 1970), Cobbinshaw Limestone of West Lothian (Forsyth 1970) and Hurlet Limestone of the Central Coalfield (Forsyth 1970). The equivalent position in the Midlothian Coalfield is the Gilmerton Limestone (Tulloch and Walton 1958).

The correlation of the Longcraig Upper Limestone with the Hurlet Limestone is an important one since the base of the Lower Limestone Group is taken as the base of the Hurlet Limestone (Macgregor 1960). The Hurlet Limestone is commonly regarded as the first widespread marine limestone in the Scottish Carboniferous succession (Macgregor and Macgregor
1948; Macgregor 1930; Francis 1965) but it is believed that this concept is the result of confused correlations (e.g. compare MacNair and Conacher (1914) and Hinzman et al (1920)). The marine transgression, in which the Hurlet Limestone was deposited, was however unusual in that it advanced across and deposited on a disconformable surface (see section IID9). The confusion in previous correlations is to a large extent the result of failure to recognise the nature of this surface and its importance as a guide to the Hurlet position.

The Longcraig Upper Limestone is correlated with the Eelwell Limestone of Northern England (Gunn 1898; Clough et al 1910; Fowler 1926). In the north of England the $P_1 - P_2$ boundary is drawn at the base of the Oxford Limestone (Johnson 1959) which lies 100m below the Eelwell Limestone and is separated from it by six marine horizons (Fowler 1926). In Scotland the boundary has arbitrarily been placed at the base of the Hurlet Limestone (Currie 1954). The boundary in Scotland thus appears to be drawn at too high a level but it is possible that the English position may be too low (Hicks 1959).

IID9 Longcraig Middle Limestone

A feature of the Hurlet correlation advanced above (section IID8) is the common occurrence in successions of a creamy nodular marine limestone lying almost immediately below the Hurlet position e.g. Longcraig Middle Limestone of Dunbar and Aberlady (Clough et al 1910), St. Monance White Limestone of St. Monance (Geikie 1902; Tait and Wright 1923; Forsyth and Chisholm 1968), Blackbyre Limestone at Inchinnan,
Bridge of Weir and Howood (Forsyth and Wilson 1965), White Nodular and Coral Limestones of Corrieburn (Macgregor et al. 1925), Bannock Limestone E of Todholes near Stirling (Dinham and Haldane 1932; Read 1971), White Nodular Limestone of Carluke (Hinxman et al. 1921), White Coral Limestone of Birkwood (Hinxman et al. 1921), Lower Crichton Limestone of Midlothian (Tullock and Walton 1958). The top of these limestones can occasionally be seen to have been brecciated or eroded e.g. at Dunbar (Clough et al. 1910; section IIIB2), Birkwood (Hinxman et al. 1921) and Carluke (Hinxman et al. 1921) and where the creamy limestones are separated from the shales and limestones of the Hurlet transgression the intervening strata consist of a coal and creamy to greenish coloured ganisters or fireclays which may be up to 10m thick but are usually less than 1m thick. The colouration at St. Monance (Tait and Wright 1923) and at Inchinnan (Forsyth and Wilson 1965) has been interpreted as the result of subaerial weathering and it is suggested that this explanation can also be applied to the other localities. In some cases the leaching has not affected the lower parts of the limestone which retain a grey colouration e.g. at Inchinnan (Forsyth and Wilson 1965), Corrieburn (MacGregor et al. 1925) and Todholes, Stirling (Dinham and Haldane 1932; Read 1970). All the above limestones are regarded as belonging to the same horizon and it is suggested that shortly after their deposition uplift occurred, overlying sediments were eroded away and the limestones subjected to subaerial weathering. The ganisters and fireclays represent residual and wash deposits on this surface.

In successions in which a creamy nodular marine limestone does not occur a correlative horizon can be recognised and is separated from the
Hurlet Limestone by up to 55m of strata which have protected it from the effects of weathering. Examples of this type include the Blackbyre Limestone of Hurlet, Paisley and Nethercraigs (Macgregor et al 1925; Forsyth and Wilson 1965), the Balgrochan Beds of Milngavie and Campsie (Macgregor et al 1925; Forsyth and Wilson 1965), the Goniatite - Lingula Limestone of Touchadam near Stirling (Dinham and Haldane 1932; Read 1971), the Blackbyre Limestone of the River Calder (Hinckman et al 1921), the Under Limestone of West Lothian (Carruthers et al 1927), the Bone Bed Limestone of Midlothian (Tulloch and Walton 1958) and the Duloch Under Limestone of West Fife (Forsyth 1970). The protective veneer may be either shale and sandstone deposited over the limestone prior to uplift, or local deposits developed on the uplifted surface or a combination of both. Examples of the first type of succession occur in Midlothian (Tulloch and Walton 1958) and in the River Calder section (Hinckman et al 1921) and an interesting feature of the River Calder sequence is the occurrence of limy concretions in creamy silty sandstones at the top of the succession. Pocket deposits are present at Nethercraigs where they have an erosive base on the Blackbyre Limestone (Macgregor et al 1925) and at Touchadam near Stirling (Dinham and Haldane 1932; Read 1971). Both these successions contain calcareous concretions in their upper parts and they also have a high content of volcanic detritus suggesting that the Clyde Plateau Lavas had been exposed during the uplift and erosion. The Duloch borehole section (Forsyth 1970) is an example of a compound sequence in which the Duloch Under Limestone and 11m of pre uplift sediments are unconformably overlain by 11m of post uplift sandstone siltstone and seatearth. The top 12m of the pre uplift sediments have been leached and contain limestone nodules (Forsyth 1970). Probably the most interesting
example of post uplift sediments are the White Limestone of Hurlet and the Baldernock Limestone of Campsie and Milngavie (Macgregor et al 1925, Forsyth and Wilson 1965) which are freshwater limestones and shales containing *Carbonita* spp, plant and fish remains. At Campsie they rest unconformably on 2.5m of shale which overlie the Balgrochan beds but at Hurlet and Milngavie they are separated from the Blackbyre Limestone (= Balgrochan beds) by thicker sequences of pre uplift sediments (Macgregor et al 1925; Forsyth and Wilson 1965). The thick fireclay and ganister sequences developed over the White Limestones of Carluke and Braidwood (Hinxman et al 1921) may represent a condition in which post uplift deposition has occurred rather late and after the limestone has been subjected to a period of weathering. In both the above successions creamy nodular weathered beds also occur at the top of the fireclay sequence.

Confusion in previous classifications has resulted from correlating and interpreting the creamy nodular horizons as a depositional unit within a cyclic sequence, rather than in the present manner where they are interpreted as characterising the weathered zone of a disconformable surface.

No evidence of the disconformity has been found in the Berwick on Tweed succession and the Longraig Middle Limestone may be tentatively correlated with the first marine limestone below the Belswell Limestone (Fowler 1926).
IID10 **Longcraig Lower Limestone**

This limestone lies at about the position of the Pathhead Marine Bands of St. Monance (Forsyth and Wilson 1968). These two horizons are only separated by a few metres of strata and since the Longcraig Lower Limestone contains a central shale with fish coprolites and *Lingula* sp. (Clough et al 1910) it may be equivalent to both of these marine bands. Other successions in the Midland Valley show up to four marine bands below the Blackbyre Limestone or its equivalent. While correlations can be established within basins correlations between basins are highly tentative and it would be premature to attempt a regional correlation of this horizon. The correlation with the Berwick on Tweed succession is also debatable as several marine horizons occur below the Kelwell Limestone (Fowler 1926).
III THE MUDSTONE AND SKATERAW UPPER LIMESTONE

IIIA) Introduction

A brief account of these horizons has already been given (section IIB8) and this description is here expanded and extended to consider aspects of the depositional environment of the shale.

IIIB) The Skateraw Sequence

IIIB1) General

The succession at the name locality of the Skateraw Upper Limestone provides the reference section for the area. The mudstone can be subdivided into an upper mudstone (600mm) and a lower shale (300mm) unit and the Skateraw Upper Limestone consists of two leaves - an upper crinoidal limestone (310mm) and a lower limy ironstone (80mm) - separated by a thin shale (70mm).

IIIB2) The Shale

The basal 300 mm of the Skateraw sequence consist of a calcareous shale. Fresh material is brownish grey in colour and weathers to a lighter colour. Joints and bedding surfaces are often marked by an irregular ochreous stain. The shale is not well laminated but splits along the bedding without the markedly irregular surface characteristic
of the overlying mudstone. Small siderite nodules (30mm in diameter) occur and Zoophycos laminae have also been found.

In thin section there is seen to be a high content of finely comminuted fossil debris (up to 50% close to the base) and crinoid, bryozoan, ?trilobite, productid and other brachiopod debris can be identified. Shell fragments tend to be aligned parallel to the bedding but there is no well defined bedding laminaion. Finely divided pyrite is sparsely distributed throughout the unit but neither siderite nor bioturbation has been observed in thin section.

The base of the shale is separated from the uppermost band of the Skateraw Middle Limestone (bed a) by a thin breccia zone of tectonic origin (see sections IIIB3 and IIC) and at its top the shale passes up into the overlying mudstone. The characters of the shale closely resemble those of bed a, differing only in the higher content of clay minerals and the upward transition into the mudstone is also marked by an increase in the clay content.

IIIB3 The Mudstone

The shale unit is overlain by and passes up into 600mm of dark brownish grey mudstone. In hand specimen the mudstone is very uniform in colour and is completely non-fissile breaking with an irregular surface, though friable weathered material may reveal a fine flaky texture. Zoophycos laminae occur and in some cases are preserved in siderite which also occurs as subspherical nodules (up to 60mm in diameter).
Pyrite occurs in occasional blobs and linear streaks.

In thin section the fossil content is generally low (about 5 - 10%) and fragments are both randomly distributed throughout the mudstone and concentrated in occasional thin layers. Fossil fragments are usually small though large fragments of both shell and crinoid material do occur. Fine granules and streaks of pyrite occur throughout the unit. Apart from the fossil layers there is no obvious bedding texture. Zoophycos laminae and other burrowing features are found at all levels though Zoophycos is particularly common towards the top where laminae extend down into the mudstone from the overlying ironstone.

The gradual upward transition from the mudstone to the ironstone is marked not only by the increased bioturbation but also by an increased content of fossil debris and siderite.

IIIBb) The Skateraw Upper Limestone - Ironstone

A buff-brown calcareous ironstone is developed above the mudstone and forms the lower leaf of the Skateraw Upper Limestone. The siderite occurs both as small well defined cigar shaped nodules (maximum length 25mm) and in the ground mass. The distribution in the ground mass is rather patchy giving the bed an irregular concretionary appearance. Weathered surfaces have a rusty brown colour and contain abundant trace fossils.
In thin section the fossil content is high (about 30%) and large fragments of crinoid and shell material are common. Bioturbation is clearly evident and fossil material (sometimes size sorted) is often concentrated in burrows. Zoophycos laminae with characteristic gutter shaped spreite are particularly evident (fig 12).

IIIB5) Skateraw Upper Limestone - Shale Parting

The ironstone is sharply overlain by 70mm of well laminated grey shale which appears to be almost unfossiliferous though a few asaphrentid coral and crinoid fragments have been found. The shale weathers back between the two leaves of the limestone and it has not been possible to obtain specimens for thin sectioning.

IIIB6) Skateraw Upper Limestone - Crinoidal Limestone

The uppermost 310 mm of the Skateraw sequence consist of a dark grey crinoidal limestone. The limestone forms a single hard compact post and has sharp contacts with both the underlying shale and the overlying mudstone. Large blocks of this limestone were used to build the now tumbled-down harbour wall at Skateraw and these blocks frequently display their lower surface which carries abundant traces of simple linear and curved burrow systems. A small (300mm diameter) Lithostrotion colony has been seen on the upper surface.

A thin section (fig 13A) shows that the limestone contains about
30 - 40% of fossil debris set in a micritic matrix. The commonest fossils are medium sized crinoid ossicles and the limestone can be classified as a crinoidal mudstone (Cain 1968) or a biomicrite (Folk 1962). The fossil debris is concentrated in thin irregular layers which appear to have been considerably disturbed by bioturbation. Occasional small granules of pyrite occur and may be concentrated along microstylolitic sutures.

IIIB7) Material Examined
At Skateraw it has been possible to extract and make detailed collections of macrofossils from a complete succession of both the mudstone and the shale unit.

IIIC) The Catcraig Sequence
The succession at Catcraig is almost identical to that at Skateraw and needs little extra description. The basal shale (300 mm) differs only in the occurrence of occasional dark fossil-free laminae (fig 13b) which have no internal structure. Unfortunately the shale is highly shattered and it has been impossible to extract this part of the Catcraig sequence. The Catcraig area is one of structural complexity (see section IIIC) and it is possible that the shattering like the breccia zone separating the shale from the Skateraw Middle Limestone is a tectonic effect. The mudstone unit (700mm) which has been fully sampled is also very similar to its Skateraw counterpart (fig 13c) though in hand specimen it appears to be slightly more fissile.
The ironstone leaf of the Skateraw Upper Limestone at Catcraig is thicker (120mm) than at Skateraw and has an irregular flaggy appearance. The remaining parts of the Skateraw Upper Limestone differ only in thickness - shale 20 mm, limestone 340 mm.

IIID) The Dunbar Works Sequence

IIID1 General

The Dunbar Works sequence is much thicker than either the Skateraw or Catcraig sequence and there are also lithological differences which are described below. In ascending order the sequence consists of mudstone (4.5m), sideritic ironstone (1m), crinoidal limestone (0.5m) and Lithostrotion limestone (0.8m).

IIID2 The Mudstone

The mudstone (4.5m) at Dunbar Works is a hard, greyish brown, non-fissile rock which weathers rapidly to a lighter grey colour. Pyrite is common in hand specimens where it usually preserves burrow systems and infills shells (see sections Hgl and IVF). Siderite is also common and occurs as burrow fills and replacements or as nodules which vary widely in size and shape up to subdiscoidal concretions which are 450 mm in diameter. Nodules and resistant fossils are often associated with local slickensiding and good examples of conical slip marks similar to those described as Guildmites (Woodland 1964; Wood 1965) have been found. Small fossil rich layers occur occasionally at the base and become thicker and more frequent towards the top where crinoid...
ossicles are also more common.

In this section the rock has a uniform appearance and the main differences are due to variation in the proportion of fossil material (figs 11A, B). Bedding planes are picked out by thin concentrations of fossils and by flat lying bryozoan fronds which occur at all levels. Pyrite is common as granules and streaks.

III.D3) Sideritic Limestone

The lowest bed of the Skateraw Upper Limestone at Dunbar Works is a siderite rich crinoidal limestone (1m). The rock is dark grey in colour and weathers to a soft friable mass from which fossils can easily be extracted. The siderite occurs as nodules and associated with Zoophycos laminae and other trace fossils.

In thin section the rock is seen to have a high fossil content (40%) which is irregular and disturbed by bioturbation. Pyrite occurs as occasional fine granules.

III.D4) Crinoidal Limestone

The Skateraw Upper Limestone at Dunbar Works contains a central post of hard crinoidal limestone. When fresh the limestone is dark to light grey in colour but weathered surfaces usually have a rusty brown or buff-coloured appearance.
In thin section (fig 11C) the fossil content is seen to be high (greater than 45%) and is dominated by crinoid ossicles. The fossil debris is not well orientated though there are large numbers of grain contacts which suggest that the rock is a grain supported biomicrite belonging to the 'muddy crinoidal limestone' group of Cain (1963) and that deposition occurred in a fairly high energy environment.

IIID5) Lithostrotion Limestone

The uppermost part of the Skateraw Upper Limestone at Dunbar Works is a bed of Lithostrotion limestone (0.8m). The bed, which appears to be composed of an extensive colony in life position, is impersistent and only occurs in that part of the quarry where the succession is thickest. The matrix between the corallites is an apparently unfossiliferous micrite.

IIID6) Material Examined

At Dunbar Works it has unfortunately not been possible to extract a complete succession of the mudstone unit. The parts of the succession examined were (measuring from the base of the Skateraw Upper Limestone) 0 - 540 mm, 750 - 1140mm, 1550 - 2180mm and 2980 - 3720mm. Material at the base (3720 - 4500mm) was lost due to shattering associated with the formation of the breccia between the mudstone and the Skateraw Middle Limestone (see section IIC) and the mudstone between 2180mm and 2980mm was also too well jointed to be extracted. The latter instance resulted from the intersection of the column with a westerly dipping
low angle (20°) shatter zone. The two upper gaps (540 - 750mm and 1140 - 1550mm) result from the occurrence of large siderite nodules in the column. Both nodules were surrounded by zones of well jointed and slickensided mudstone which proved impossible to sample.

IIIE) Facies Relationships

The suggested facies relationships are illustrated in Fig 15. The Catcraig and Skateraw sequences are so similar as to leave no doubt as to their correlation. The basal shale at these two localities is not represented at Dunbar Works where the lateral equivalent is believed to be the lower part of the mudstone. The sideritic lower posts of the Skateraw Upper Limestone at each of the three localities are also believed to be equivalent and this is supported by the interpretation of their origin (Section IIIG2). The crinoidal limestone posts at the three localities are also equated though it is not clear whether the absence of the shale band at Dunbar Works is due to non-deposition, erosion or facies variation. The Lithostrotion Limestone at Dunbar Works is a local development in the top of the Skateraw Upper Limestone and the small colony in the top of the Skateraw Upper Limestone at Skateraw may be contemporaneous.

IIIF) Thickness of Beds

Isopach maps of the mudstone, the Skateraw Upper Limestone and of the two combined are illustrated in figures 9, 10 and 11. All three maps show maximum thicknesses and thickness variations in the
centre of the area and local maxima are arranged in a linear pattern giving a complex WNW - ESE aligned accumulation. The thickness of the mudstone is generally lower to the north of this feature which has a steep north face (fig 9). Local maxima on the feature are separated by cross cutting zones of reduced accumulation which are often very steeply sided (fig 9). The Skateraw Upper Limestone (fig 10) is thinner to the south of the line of maximum thickness and isopachytes are more closely spaced on this side of the accumulation belt. The isopachs of the mudstone and Skateraw Upper Limestone combined (fig 11) are most similar to those of the mudstone due to the greater contribution which this bed makes to the total thickness.

There is no relationship between the isopach patterns and the configuration of the upper surface of the Skateraw Middle Limestone (fig 7). This suggests that the thickness variation of the mudstone and Skateraw Upper Limestone has not been controlled by structural features though some slight modifications may have occurred as a result of thrusting associated with the NNW - ESE minor structures (see section IIC). It also suggests that the mudstone and Skateraw Upper Limestone were deposited on and accumulated over a more or less planar surface rather than as sediment infill to localised depressions. At Dunbar Works the upper surface of the Skateraw Middle Limestone is a more or less uniform plane with only a slight dip while in the north quarry wall, which provides a section through the flank of the zone of maximum thickness, the upper surface of the Skateraw Upper Limestone can be seen to have a plicated character with crests and valleys. At both Cat Craig and Skateraw there is little or no variation in the
thickness of these beds. The isopach maps of the mudstone (fig 9) and of the combined thickness (fig 11) are therefore interpreted as reflecting the palaeorelief which existed during the deposition of these beds. The zone of maximum thickness is believed to have been a linear bank-like elevation above the surrounding areas. The Skateraw and Catcraig successions lie in the off-bank areas while the Dunbar Works sequence lies on the bank complex close to one of the maxima. The present compacted thickness difference between these successions (about 5.5m) underestimates the true palaeorelief which existed at the close of deposition of the Skateraw Upper Limestone.

III(G) Genesis of siderite and pyrite

IIIG1) Pyrite

Pyrite occurs in the mudstone at all three localities and finely disseminated granules are probably responsible for the dark colouration of the rock. The most common mode of occurrence of pyrite is as linear streaks of finely divided material which represent collapsed burrow systems (see section 1VP) and a few examples of transitions from a flat layer into a short cylindrical segment of crystalline pyrite have been found at Dunbar Works. Pyritised burrows are most common at Dunbar Works where more complex pyritised burrow systems have also been found (see section 1VP). Pyrite is also common filling shells and the stereom of crinoid ossicles. At Dunbar Works small octahedra and spherical aggregates of pyrite crystals occur and have often developed as encrustations on bryozoan, crinoid and shell
fragments. Siderite nodules have occasionally been observed to enclose pyrite crystals and spheres.

Pyrite forms as the result of reaction of ferrous and sulphate ions in a reducing environment (Curtis and Spears 1968, Berner 1970) and in recent sediments occurs as an early diagenetic mineral (Love 1967) especially where there is bacterial activity. In the mudstone the relationship with siderite (see section IIIG2) and the occurrence as burrow fills suggests an early diagenetic origin and the association with shells and burrows may indicate bacterial degradation of animal tissues and mucous linings.

III(G2) Siderite

Siderite in the mudstone and Skateraw Upper Limestone occurs in three ways - firstly as isolated and often sharply defined nodules, secondly as burrow infills and replacements associated with Zoophycos, 'burrowed ironstone nodules' and 'halo' burrows (see section IVP) and thirdly as a diffuse nodular groundmass associated with the lower ironstone or sideritic limestone leaf of the Skateraw Upper Limestone. Slickensiding indicates that all three types have resisted compaction which suggests that they formed at an early stage in diagenesis. This is also suggested by the filling of burrows and by the occurrence of undeformed shells in the nodular types. Siderite nodules may contain pyrite crystals showing that they have formed later in the diagenetic sequence.
The ironstone leaf of the Skateraw Upper Limestone with its early diagenetic origin, association with extensive bioturbation, and sharply defined upper surface is similar in character to the sideritic bands of the Yorkshire Lias. The genesis of these beds has recently been described by Sellwood (1971) and a similar origin is proposed for the ironstone at Dunbar. Iron oxides became concentrated near a bioturbated and oxygenated sediment / water interface during a phase of reduced sedimentation. Rapid burial on renewed sedimentation allowed the development of reducing conditions in the bed and by preventing access of sulphate ions from sea water inhibited formation of pyrite. The ferrous ions reacted with carbon dioxide to form siderite.

The occurrence of siderite in the mudstone as nodules and burrow fills may represent similar but shorter periods of reduced sedimentation though no prominent nodule horizons have been observed. Siderite can however also form as a subsequent stage to pyrite in conditions of rapid sedimentation and high iron concentration. In this environment pyrite would develop in association with organic matter and burrow systems close to the sediment / water interface where sulphate ions were available. Rapid burial would however half the supply of sulphate ions and pyrite formation would become inhibited. The surplus ferrous ions in these deeper layers could then react with carbon dioxide to form siderite. Organic matter and mucous linings associated with deeper burrows appears to have formed a particularly favourable site for sideritisation.
Depositional Sequence

The interbedding of the mudstone with carbonate rocks suggests that the dominant sedimentological control has been the availability of clastic material. The mudstone sequence was initiated by an influx of fine mud which appears to have been a widespread event affecting sequences in Midlothian, Fife and perhaps elsewhere (see correlation in section IID6). Though mudstones developed in the bank area the formation of shales in the off-bank areas suggests that deposition was at first rather slow. Subsequently the supply of sediment appears to have increased with time and increasingly rapid accumulation led to the formation of mudstones even in the off-bank areas. This rapid accumulation is also indicated by the pyrite-siderite diagenetic sequence though the occurrence of thin fossil rich laminae may indicate fluctuations in the environment and the development of more agitated deflationary conditions.

The deposition of the mudstone appears to have been terminated by failure of the sediment supply and a period of minimal sedimentation led to the formation of the lower siderite leaves of the Skateraw Upper Limestone. Apart from a brief influx of clastics recorded in the Catcraig and Skateraw successions renewed sedimentation was of carbonates which formed the upper parts of the Skateraw Upper Limestone. At Dunbar Works the bank succession was capped by the growth of a coral colony.

Carbonate deposition was halted by the abrupt renewal of the supply of sediments. The renewed sedimentation was rapid and the resulting mudstones pass upwards into sandstones and siltstones typical of the
regressive phases of Scottish Lower Carboniferous cyclothems and which may thus be of deltaic origin (Goodlet 1959, Greensmith 1966). Carbonate deposition had also occurred in Midlothian where indeed it probably persisted for a considerably longer period but in East Fife there appears to have been no cessation in the sediment supply. Sequences in West Fife, at Invertie1 and Seafield, are similar to those at Dunbar but indicate several alternations of clastic and carbonate deposition.

Features of the depositional history and in particular the generative cause of the bank structure are considered further in section VI.
IVA) Introduction

The main purpose of this section is to discuss the palaeoautecology of the macrofauna and macroflora of the mudstone. Each species (or larger taxon) is examined in turn and features of its palaeoautecology and taphonomy are reconstructed using information obtained directly from the mudstone combined with information gathered from recent and fossil sources.

Whittington (1964) has emphasised the need for palaeoecological research to be based on a sound foundation of careful taxonomic work and thus, where relevant, comments of a systematic nature have been included within the discussion. Detailed systematic descriptions have however been separated as an appendix in order to avoid large and purely descriptive hiatuses within the development of this section. A more complete separation between the taxonomic and the palaeoecological aspects has not been made as there is in addition to the above mentioned necessity a reciprocal need for taxonomists to appreciate palaeoecological and taphonomic features.

One of the problems of this study has been delimiting the macrofauna and macroflora. The distinction between microfossils and macrofossils is generally made using the criterion of visibility to the naked eye (Jones 1956, Gary et al 1972) and this criterion has been used in the classification of fossils from the shale. Under optimum conditions the
human eye can resolve lines which are only 1/240" (approximately 0.1mm) apart (Malies 1959) but in palaeontological studies factors such as mode of preservation, contrast between fossil and matrix, texture of matrix, strength and angle of illumination and familiarity of the observer with his material will all influence the level of resolution which is obtained. In practice the critical size will vary from species to species but probably falls close to the 2 mm boundary used by Craig (1954). Introduction of the size criterion poses several problems since it may cut across natural biological divisions. For instance in certain cases species from dominantly micropalaeontological groups such as ostracods, foraminifera or scolocodonts should be considered as macrofossils while more seriously juvenile stages and skeletal parts and fragments of macropalaeontological groups should be considered as microfossils. Consequently the size definition has not been rigidly adhered to and where useful essentially microfossil evidence has been included.

A general faunal list for the mudstone and the Skateraw Upper Limestone is given in table 3 and the detailed distribution of fossils in the mudstone at the three localities is tabulated in the enclosures in the pocket at the back of the volume.

IVIB) Phylum Protozoa

Foraminifera were common in washed residues from all three localities but have not been extensively studied. Encrusting foraminifera (? Stachelides polytrematides (Brady)) have been observed on crinoid
ossicles and bryozoan fragments in washed specimens from Dunbar Works. Not all specimens were still associated with their substrate but these free specimens all appear to have encrusted regular cylindrical objects such as crinoid columnals.

The macroscopic species, *Saccaminopsis fusulinaformis* (M'Coy), which may not be a foraminiferan (Cummings 1961), has been found in hand specimens from Catcraig and Skateraw. At Skateraw, though not subsequently found in the column, this species was found in the trimmed material in a localised aggregation on a bedding plane 0.2 m below the top of the mudstone. All the specimens are individual flasks and are usually crushed by compaction though some were preserved intact in a small ironstone nodule. The flasks in the nodule were infilled with calcite. At Catcraig a similar group of crushed flasks was found but its position in the sequence is not known. Two isolated individuals were found in the basal shale at Catcraig (supplementary collection). The aggregations are reminiscent of the lensoidal accumulations which have coalesced to form the *Saccaminopsis* band of the Skateraw Middle Limestone and may indicate a brief return to conditions similar to those which prevailed during the formation of the *Saccaminopsis* band. *Saccammina carteri* Brady (= *Saccaminopsis fusulinaformis* (M'Coy)) has been recorded from Skateraw and also from Oxwell Mains by Clough et al (1910).

IVC) Phylum Porifera

IVC1 Hexactinellid sponge

Portions, which may be up to 100 mm long, of the anchor rope of a
lyssacine hexactinellid sponge have been found on hand specimens and in the column from Dunbar Works. The ropes are composed of loose bundles of long hair like spicules which are up to 15 mm long and which average 0.1 mm in diameter. These basilia are similar to the spicules of *Hyalostelia parallela* (M'Coy) described by Hinde (1887) though terminal processes have not been observed. However, as Reid (1968a) has emphasised, it is dangerous to identify a sponge solely on the basis of its basilia and thus no specific assignment has been made.

The anchor ropes are unlikely to have survived extensive transport and it is believed that the sponge was endemic to the Dunbar Works locality. The absence of aggregates of body spicules may be due to the body, whose spicules were probably not firmly united, being more susceptible to decay and disintegration.

The ecology of recent sponges has been summarised by Laubenfels (1957) and by Reid (1963b). While modern Calcarea have a generally shallow water habit lyssacine sponges are generally found in deep water and are only known from water shallower than 50m under the ice off Antarctica (Laubenfels 1957; Reid 1968b). Reid (1968b) has also reviewed the distribution of Upper Palaeozoic sponges which are known principally from the work of Finks (1960) who has been able to recognise a depth zonation of calcareous (shallow shelf and reef areas) and siliceous (deep basinal areas) in the Midland and Delaware basins of Texas. A few lyssacine sponges, notably genera closely related to *Hyalostelia*, are known in the shelf zone in the quieter and deeper but still well
aerated parts of the sea floor' (Finks 1960). The depth of these occurrences is estimated to be about 30 - 50m (Reid 1968b) but even shallower depths of a few metres are indicated by a lyssacine sponge recorded by Zangerl and Richardson (1963) Reid (1968b). The occurrence of a lyssacine sponge at Dunbar thus gives little indication of depth but does suggest a fairly quiet environment.

IVC2 Clionolithes sp.

Small radiating and dichotomising borings of Clionolithes type have been observed etching the surface of crinoid plates from the Skateraw Upper Limestone. Such excavations are notoriously difficult to identify but may indicate the action of clinoid sponges. Sponge borings have been recorded from the shale at Oxwell Mains by Clough et al (1910) but neither their nature nor their host is mentioned.

IVD) Phylum Coelenterata

IVD1 Introduction

The mudstone and Skateraw Upper Limestone contain a quite diverse fauna of small corals and to avoid unnecessary repetition and cross referencing the discussion of general points of coral ecology has been placed in a separate section (IVD12). The coelenterates are also represented by two other minor faunal components - a hydroid and a conularid.
IVD2 **Allotropiophyllum tuberculatum**

This rugose coral occurs occasionally in the mudstone and Skateraw Upper Limestone at Dunbar Works and at Catcraig but has only been recorded in the column from the former locality. *Allotropiophyllum tuberculatum* (Thomson) has been recorded in the Dunbar area from Catcraig, East Barns Quarry and Skateraw by Hill (1940) and these specimens were probably derived from the mudstone or the Skateraw Upper Limestone.

The adapical portions of the coralla are characterised by the development of radiciforme processes which probably served to fix and stabilise the animal on the soft mud bottom. The maximum length of these epithecal outgrowths which has been observed is 3 mm but all processes terminate in a fractured surface. Where apices are clearly visible they are seen to have been distorted by attachment to a hard object which can in some cases be identified as a fenestellid frond or a crinoid ossicle. Slight growth swellings and constrictions though characteristic of the species (Hill 1940) may indicate minor fluctuations in the environment.

A specimen from the Skateraw Upper Limestone at Dunbar Works has been encrusted by *Spirorbis ambiguus*.

IVD3 **Claviphyllum carruthersi**

This species originally described by Hill (1940) as *Fasciculophyllum carruthersi* but subsequently transferred to *Claviphyllum* by Hudson (1942) is based on material derived from the mudstone though the type locality -
recorded as East Barns or Skateraw (Hill 1940) - is uncertain. In the present study the species is rare and has only been found at Callcraig (supplementary collection).

One specimen is encrusted with several indeterminate spirorbids. The nature of the apex is unknown.

IVD1 L Claviphyllum eruca

This small slim coral is common in the Skateraw Upper Limestone at Dunbar Works but has not been recorded in the mudstone or at either of the other two localities. According to Hill (1940) Carruthers found Fasciculophyllum eruca (M'Coy) (= Claviphyllum eruca (M'Coy)) in the shales above the Skateraw Middle Limestone at East Barns but it would seem more likely that these specimens were in fact derived from the Skateraw Upper Limestone.

The Dunbar specimens are smaller - maximum length 27 mm - than the museum specimens on which Hill (1940) based her redescription as the longest corallum which she observed attained a length of at least 50 mm. Like Hill's material the Dunbar specimens may show marked rejuvenescent features and in several cases growth can be seen to have resumed despite extensive damage to the walls of the calice, which may indicate that the Skateraw Upper Limestone formed under fairly turbulent conditions.

The apical portion of coralla often appears to have been lost prior to burial but in some individuals it can be seen that there was a juvenile
phase of attachment to bryozoan fronds or fragments.

IVD5 Lithostrotion sp.

As previously mentioned (section IIID5) an imperssistant small bioherm of Lithostrotion sp caps the Skateraw Upper Limestone at Dunbar Works. The colony occurs where the succession is thickest and thus developed at the point of maximum elevation in the area (see section IIIF).

A small Lithostrotion colony has also been observed on the upper surface of the Skateraw Upper Limestone at Skateraw.

IVD6 'Zaphrentis' constricta

Specimens of a coral belonging to the 'Zaphrentis' delanouei group are fairly common in the mudstone at all three localities. They are also common in the Skateraw Upper Limestone at Dunbar Works and are found in the lower leaf of this limestone at Catcraig. Individuals from each locality were sectioned and revealed the septal pattern of 'Zaphrentis' constricta which is characteristic of the Lower Limestone Group of the Scottish Carboniferous (Carruthers 1910). No further attempt has been made to study the variation and ontogeny of the septal patterns of this species. Carruthers (1910) in his study used material from the shale above the Skateraw Middle Limestone of four localities in the Dunbar area - East Barns Quarry, Catcraig, Skateraw and Burlage Quarry. The exact location of Burlage Quarry is uncertain and the name is not used or recognised in the district at the moment. The position indicated on Carruthers (1910) small scale index map suggests that it was one of the
small quarries formerly exposed to the west of the present opencast workings. The average variant percentages recorded for the district are delancuei 1, parallela 3, constricta 77 and disjuncta 19 (Carruthers 1910).

Most specimens of Z. constricta are found with their long axis in the horizontal plane and this is essentially the attitude which they would adopt either as an adult life position or as a mechanical orientation of dead coralla (the life position may in fact be to some extent a mechanical orientation). It is thus difficult to assess the status of any particular specimen but most if not all are thought to be in a post-mortem orientation. Of the few coralla found at a high angle to the bedding most have their calicular opening down and are clearly not in a life position.

The azimuthal data for Z. constricta in the columns of the three localities is given in table 4. The Dunbar Works orientation shows a maximum mode of apices pointing in a WNW direction and smaller more diffuse secondary modes in SSW and NNE directions. The major mode is believed to result from orientation of coralla to a current with a WNW - ESE lineation. The direction of current flow is however difficult to determine. Experiments by Richter (1929) show that in Calceola apices point down stream and similar results have been obtained with the gastropod Nucella (Kelling and Williams 1967) but, in experiments with Turritella, Brenchley and Newall (1970) found a very strong orientation of apices upstream. The secondary modes may result from concentrations of coralla lying across the current but their
asymmetric nature may indicate the existence of a cross current
with a SSW - NNE lineation.

The orientation data available for Skateraw and Catcraig is
rather limited and in the case of Skateraw is probably too small
for analysis. The Catcraig orientations give some indication of a
similar current regime to those at Dunbar Works.

IVD7 *Zaphrentis* curvilinea

Specimens of this coral occur occasionally in the uppermost
30 cm of the mudstone at Dunbar Works (supplementary collection) and
are also found in the Skateraw Upper Limestone of the same locality.

This species is the largest solitary coral in the fauna and the
size of the largest specimen - 95 mm long and 43 mm in calicular
diameter (crushed with) accords well with the maximum dimensions
quoted by Hill (1940) which were 90 mm and 40 mm respectively.

The characters of the apex are unknown.

IVD8 *Auloporoid* sp.

Crinoid columns and fragments of trepostome bryozoa from the
Skateraw Upper Limestone at Dunbar Works are occasionally encrusted
by an auloporoid coral. The small reptant dendroid colonies are made
up of long (up to 2 mm) conical corallites which generally remain closely
adpressed to each other and reach a maximum diameter of about 0.3 mm,
at their aperture. The internal characters of the corallites are not known.

The time of encrustation relative to the death of the host is unknown. The colonies have never been found encrusting articular or fracture surfaces but equally the host is never seen to have reacted to or overgrown the colony.

IVD9 Cladochonus bacillarius

Fragments of Cladochonus bacillarius (M'Coy) are common in the Catcraig column but elsewhere have only been rarely found in the mudstone and Skateraw Upper Limestone at Dunbar Works (supplementary collections). No complete colonies have been found though specimens from Catcraig may attain a length of 40 mm. Hudson et al (1966) record that C. bacillarius has an early attached phase on crinoid stems but no specimens of the encrusting phase have been found.

IVD10 Emmonsia aff parasitica

This small coral appears to be identical to the specimens described by Thomson (1883) and assigned by him to Favosit es parasitica (Phillips) (= Emmonsia parasitica (Phillips)) but as noted by Smith and Gullick (1925) they differ from E. parasitica in several characters. Though possessing the globular shape and attached habit of Emmonsia parasitica the Scottish species is smaller in size with an average diameter of 5 mm and a maximum size of 9 mm (E. parasitica - average = 15 - 25 mm, maximum size = 50 mm; Smith and Gullick (1925)). Of the internal features mural
pores are present and are smaller (0.15 mm) than those of *E. parasitica* (0.25 mm) but neither squamulae or tabulae have definitely been recognised. If squamulae and tabulae should prove to be absent then it may be necessary to transfer the species to another genus (perhaps *Pseudofavosites* Gerth).

The species is fairly common in the mudstone at Dunbar Works, where it has been recorded on several occasions in the column between 950 and 3030 mm, and is also found in the Skateraw Upper Limestone at the same locality. A single specimen was found in the column at Skateraw and only one colony has been found at Catcraig (supplementary collection). *Favosites parasitica* (Phillips) has been recorded from Skateraw by Clough *et al.* (1910).

*E. aff parasitica* like *E. parasitica* is commonly found encrusting crinoid columnals though it has also been recorded (Thomson 1883) growing on producted spines. Hudson *et al.* (1966) have found clear indications that in *E. parasitica* attachment occurred during the life of the crinoid but that the coral could continue to grow after the death of the host. In the Dunbar material no evidence has been found of the crinoid reacting to encrustation but one specimen from the Skateraw Upper Limestone shows corallites infringing on the articular surface of a columnal. Some colonies show no visible means of support and their growth is difficult to explain unless one invokes, as Smith and Gullick (1925) did for similar occurrences in *E. parasitica*, a very slender (e.g. crinoid cirrus, producted spine) or perishable (e.g. seaweed) support.
Microcyathus cyclostomus (Phillips) is fairly common in the column at Catcraig and has also been found in the column at Skateraw from which locality it had been recorded by Clough et al (1910). It has never been found in either the mudstone or the Skateraw Upper Limestone at Dunbar Works though recorded at Oxwell Mains by Clough et al (1910) and at East Barns by Etheridge and Nicholson (1878) (Microcyathus cyclostomus does occur in the mudstones overlying the Skateraw Upper Limestone at Dunbar Works).

The simple colonies of this species are typically found attached to foreign bodies by a wide base though in some cases the attachment has been lost prior to burial. At Dunbar the coral has been found encrusting Zaphrentis constricta, Eomarginifera longispina, Zygopleura sp., orthocone and other indeterminate shells. Etheridge and Nicholson (1878) have also recorded Palaeacis cyclostoma (= M. cyclostomus) on crinoid stems, Chonetes, Dentalium ingens, Productus punctatus (= Echinoconchus punctatus), Bellerophon urii (= Euphemites urei) and Euomphalus carbonarius (= Straperollus (Euomphalus) carbonarius). Colonies of M. cyclostomus are found on both the internal and external surfaces of brachiopod valves and this with the occurrence on orthocone fragments indicates that the coral merely utilised dead shells for support.

Of the two specimens found in the columns at Skateraw one was detached from its substrate and lay face down while the other was attached to a large cephalopod fragment and had its calicular surfaces uppermost though inclined to the bedding at an angle of 30°. At Catcraig five specimens in the column were still attached and lay with their...
calicular surfaces uppermost and two specimens though face up had apparently become detached. Of the remaining six specimens found in the column all were face down though three were attached to shells. Of all the specimens of _M. cyclostomus_ examined only one showed any indication of growth following detachment of the colony from its substrate (Catorraig - supplementary collection).

In the material examined by Etheridge and Nicholson (1883) the majority of colonies consisted of two, three or perhaps four individuals though a range from one to twelve individuals per coralla was found. At Dunbar (table 5) only coralla with two to four individuals were found. The diameter of calices varies from 2.8 mm to 4.9 mm (average 3.8 mm) but the range in size in any one colony is small with the size difference between the largest and smallest corallites varying from 0.7 to 0.1 mm (average 0.4 mm). This suggests that the number of individuals per colony is, if not genetically defined, determined early in the astogeny. The regenerative colony mentioned above was an exception to this rule since regeneration had occurred by growth of a new corallite which was much smaller (3.1 mm) than the other three corallites (4.1, 4.2 and 4.2 mm).

**IVD12 Hexaphyllia marginata**

A single short (9 mm) fragment of _Hexaphyllia marginata_ (Fleming) has been recorded from the Skateraw Upper Limestone at Dunbar Works. The specimen which is uniform in diameter (1.5 mm) is abraded but the tubercle bases are clearly visible and are seen to be rather irregularly
spaced with little or no tendency for tubercles on different ribs to occur at the same level.

IVD13 Coral Palaeoecology

The ecology of modern scleractinian corals has been reviewed by Wells (1957a) and Stoddart (1969) but the applicability of this information to the palaeoecology of the extinct rugose and tabulate corals must be doubtful especially as the presence or absence of symbiotic zooxanthellae cannot be determined. Wells (1957b) has discussed the palaeoecology of Palaeozoic corals and concludes that in general they inhabited environments similar to those occupied at present by non-surface lagoon reef corals. This would indicate habitats in the photic zone to a maximum depth of about 50m with well oxygenated gently circulating waters which have minimum temperatures of about 16 to 21°C and which are relatively free from rapid sediment accumulation though are not necessarily clear and non-turbid (Wells 1957b). Hill (1938, 1948) has recognised three facies faunas in the Carboniferous and, with the exception of the Lithostrotiun sp and Hexaphyllia marginata, all the Dunbar coral species belong to her Cyathaxonia fauna. Lithostrotiun belongs to the reef coral fauna but the affinities of Hexaphyllia are uncertain and it has been found associated with both the Cyathaxonia fauna and the Caninid-Clisiophyllid fauna (Hill 1938).

The Cyathaxonia fauna is typical of dark shales and argillaceous or arenaceous limestones though members of the fauna may occur in lighter shales and in 'reef knoll' limestones (Hill 1938). It is
interpreted by Hill (1938) to be a deeper, colder and murkier water fauna than the other two faunas and may thus inhabit deeper and colder water than indicated by Well's (1957b) estimates. The term 'reef coral fauna' is somewhat misleading since even the most massive Carboniferous developments resemble small patch reefs rather than the large scale structures usually implied by the term. Hill (1938) reconstructs this fauna as occurring in shallow, sediment free, carbonate rich seas whose temperature was similar to or slightly cooler than modern subtropical seas.

The occurrence of *Lithostrotion* at the top of the Skateraw Upper Limestone may indicate the first stages of a new phase in the evolution of the bank complex in sediment free conditions. The further development of this phase was however truncated by the influx of sediment which formed the overlying mudstones. These mudstones contain a *Cyathaxonia* coral fauna which must have grown in essentially the same depth of water as the *Lithostrotion* sp. Though slight changes in temperature may have resulted from changes in turbidity and water mass, the relationship of the two faunas suggest that the critical control was, as indicated by their typical facies, a greater ability on the part of the *Cyathaxonia* fauna to withstand the effects of sedimentation. Some recent scleractinian corals are able to remove sediment particles from their visceral disc (Yonge 1930) and the *Cyathaxonia* corals may also have had this ability to some extent.

With the exception of the ubiquitous *Z. constricta* the Dunbar
Cyathaxonid corals show a restricted occurrence suggesting that sub-faunas may exist within the group as defined by Hill (1938). The following sub-groups can be recognised in the Dunbar area -

a) the bank limestone fauna - Z. constricta, C. eruca, Z. curvilinea, A. tuberculata, suloporoid sp - found in the Skateraw Upper Limestone at Dunbar works in what is inferred to be an almost sediment free, agitated environment. Reduced developments occur in slightly more turbid or less agitated conditions e.g. Skateraw Upper Limestone (lower left) and mudstone at Catcraig - Z. constricta and A. tuberculatum, upper parts of the mudstone at Dunbar Works - Z. constricta, A. tuberculatum and Z. curvilinea. A member of the off-bank mudstone fauna (group b), C. bacillarius, may occasionally be found in this fauna.

b) the off-bank mudstone fauna - Z. constricta, M. cyclostomus, C. bacillarius, C. carruthersi - typical of the mudstones at Catcraig and probably inhabiting moderately turbid and moderately agitated environments. Optimum conditions for the fauna do not seem to have prevailed at Skateraw where only Z. constricta and M. cyclostomus have been found. C. bacillarius may rarely be found associated with both the other Dunbar sub-faunas.

c) the bank mudstone fauna - Z. constricta only - found in the mudstones at Dunbar Works where conditions were probably quietest and most turbid. Towards the top of the mudstone at Dunbar Works
the occurrence of *Z. curvilinea* and *A. tuberculatum* indicates a transition to the bank limestone fauna. *C. bacillarius* is occasionally able to survive in the bank mudstone facies.

*E. aff parasitica* which occurs both in the bank mudstones and in the bank limestones has been excluded from these faunas. Its distribution may be explained by its association with crinoids (and other supports) which would have protected it from the effects of turbulence and sediment accumulation though some colonies may have become secondarily free and survived on the sediment surface. Basal fixation, which is typical of at least the early post-larval stages of all fossil and recent corals (Wells 1957b), may have conferred a similar protection to the juveniles of the other Dunbar corals.

**IVD11** Hydroid sp

A small species of hydroid, which is described in the appendix has been found in washings from the mudstone at Dunbar Works. The black chitinous tubes of the hydroosome are adherent on crinoid columnals, bryozoan fragments, *Eomarginifera longispina* and other brachiopod fragments. Encrustation is clearly post mortal since the species occurs on both internal and external surfaces of shells and may also grow over the zooecial apertures of bryozoa.

**IVD15** Paraconularia tubericosta

A single specimen of *Paraconularia tubericosta* (Sandberger) has been found in the Dunbar Works column and four other specimens have been
recorded from this locality. Elsewhere only a single small fragment has been found in the mudstone at Catcraig (supplementary collection). The Dunbar Works specimens have been preserved in an almost undistorted condition by infilling of ironstone which may also envelope the test to some extent. The formation of the ironstone may have been promoted by the decay of the body within the test.

Though the coelenterate affinities of conulariids have been doubted (Kozlowski 1968, Termier and Termier 1942) most authors are agreed that their life cycle includes a juvenile attached phase and an adult free swimming phase which is at least analogous to that of modern medusae. The apical regions of the Dunbar specimens are obscure but all appear to have been unattached and the species is believed to have been pelagic (Slater (1907) has recorded apical diaphragms in this species). The almost complete absence of P. tubericosta from Catcraig and Skateraw may be due to the destruction of the thin chitinous test.

IV§3) Phylum Bryozoa

IV§1 General

The mudstone and Skateraw Upper Limestone contain a rich and diverse fauna of bryozoa. Most zoaria have been extensively fragmented and much of the fine skeletal debris at all three localities is of bryozoan origin. The species list is given in table 3 but because of the fragmentation and because of the difficulty experienced in making specific determinations it has been impossible to collect bryozoa from
the columns on a specific basis.

**Fenestellid bryozoa**

Zoarial fragments of fenestellid bryozoa are common at Dunbar Works both in the Skateraw Upper Limestone and in the mudstone. Towards the base of the mudstone fragments tend to be small and inconspicuous while towards the top of the mudstone and especially in the top 300 mm they may be large and occasional bedding planes with an extensive cover of fragments occur. The largest fragment observed in the column was triangular with a base width of 70 mm and a height of 80 mm but had been truncated during the trimming of the block. In the Skateraw Upper Limestone fenestellids are again conspicuous but most fragments are extremely small.

In the mudstone at Catcraig and Skateraw macroscopic fragments are small and infrequent and have not been found at many levels.

Much has been written concerning the correlation of zoarial growth form with environment since the pioneering work of Stach (1936) and recent accounts are those of Ryland (1970) and Schopf (1969). Fenestellids have erect rigid brittle colonies and modern bryozoa with this growth form are typical of and most common at depths of 35 to 100 m in habitats not subject to appreciable water movement (Ryland 1970, Schopf 1969). The upper limit may correspond approximately to the depth of the wave base (Ryland 1970).
The functional morphology of fenestellid bryozoa has been analysed by Cowen and Rider (1972) and they are clearly well adapted to such environments of poor circulation creating and maintaining their own feeding currents and maximising their filtration area. The upright stance of fan-shaped and funnel shaped colonies, both of which occur at Dunbar, would help the colonies to shed accumulating sediment though modern bryozoa are generally intolerant of high deposition rates. Lagaaij and Gautier (1965) found that off the Rhone delta bryozoan faunas became extremely reduced in species and in numbers in the areas of moderate silt deposition (1 cm/yr, Straaten, 1960).

Palaeocorynid extensions on fenestellids have given rise to considerable controversy and are variously interpreted as parasitic hydrozoa (Duncan and Jenkins 1869), the products of symbiotic algae (Condra and Elias 1914) or as root-like appendages serving to support and stabilise zoaria (Tavener-Smith 1969, Young and Young 1874). These processes are common on fenestellid fragments from Dunbar and in washed residues from the mudstone at Dunbar Works specimens have been found terminating in adhesion to crinoid ossicles or other bryozoan fragments, which would suggest a supportive role. Other fragments in the residues show that the growth of zoaria occasionally interfered with or interacted with the growth of other bryozoan or with crinoid stems and cirri.

**IVE3 Other cryptostome species**

The non-fenestellid cryptostome species appear to be less abundant than fenestellids at all three localities but small fragments may be difficult to distinguish. The growth forms of these species are erect
rigid rod-like brittle colonies and they may have had a similar preference for non-turbulent conditions as that suggested for fenestellids (see section IVE2). The sub-vertical attitude of branches would again provide a minimum area for sediment accumulation.

Fragments in washed residues from Dunbar Works often show growth interaction with fenestellid and other bryozoans and with crinoid stems and cirri. In a few cases interaction is indicated by an apparently hollow tube running obliquely through the bryozoan stem and suggesting the existence of algae or other perishable organisms.

**IV& Tabulipora scotica**

The only trepostome bryozoan in the fauna is *T. scotica* (Lee) fragments of which are common in the Skateraw Upper Limestone at Dunbar Works and specimens of which have also been found in the mudstone at the same locality (supplementary collection).

The growth form is again an erect and rigid rod-like colony but is more robust than the delicate rod-like cryptostomes and *T. scotica* may have been able to survive in more agitated environments than these species (see IVE2 and 3). Colonies are fixed by an expanded base which has been found encrusting crinoid columnals and fragments of the same species.
**Fistulipora incrustans**

*Fistulipora incrustans* (Phillips) occurs in the Skateraw Upper Limestone and in the mudstone at Dunbar Works but though recorded from Skateraw by Clough et al (1910) has not been found at either of the other localities. Specimens from the Skateraw Upper Limestone are usually large encrustations on columnals or fragments of *Tabulipora* and may extend for axial lengths of up to 20 mm. By contrast specimens from Dunbar Works are usually small rosettes about 3 mm in diameter which have encrusted crinoid columnals or fenestellid fragments. The largest specimen found in the mudstone, one of three specimens found in the column, had initially encrusted a columnal but subsequently had spread out and colonised the sediment surface to a distance of up to 10 mm on either side of the columnal.

Encrusting bryozoa are commonly regarded as typical of shallow or intertidal areas but can occur wherever there is a suitable substrate (Ryland 1970).

**Ascodictyon radians**

A small pyritised colony of *Ascodictyon radians* (Nicholson and Etheridge) has been observed encrusting a crinoid columnal in a washed residue from the mudstone at Dunbar Works. *A. radians*, *A. stellatum* and *A. sp* have been recorded from Skateraw (Clough et al 1910).

**Phylum Annelida and minor groups**

**Scolecodonts**

Ten poorly preserved assemblages and the same number of isolated
scolecodont elements have been found in the mudstone at Dunbar Works (column and supplementary collections). Two isolated elements (one of them doubtful) have been found at Catcraig (column collection).

"The difficulty in the classification of detached "annelid" jaws has already been pointed out by nearly every writer on the subject" (Lange 1949) and Kielan-Jaworowska (1966, 1968) has argued the case for using para- and ortho-taxonomies though another recent worker Kozur (1970, 1971) has rejected the dual classification. The Dunbar assemblages and elements cannot be identified with any of the scolecodonts which have been recorded from the British Carboniferous (Hinde 1879, 1896; Eller 1967; Clarke 1958; MacDonald 1966) but, though at least four species are present in the assemblages, their preservation is not good enough to warrant the description and erection of new taxa.

The high ratio of assemblages to isolated scolecodonts is probably due to collecting bias especially as Lange (1949) in his field collections found that isolated elements were much commoner than assemblages. However Kielan-Jaworowska (1966) has shown that a cuticular stomedeum may hold assemblages together after the death of the animal and since the majority of modern polychaetes are burrowers preferring muddy substrates rich in vegetable and other organic matter (Benham 1896) the death and decay of worms in their burrows might also give a tendency for assemblages to be preserved intact. At least one assemblage has been found lying in a pyritic trace which is believed to be a trace fossil (see section IVF).
Modern polychaetes are mostly found in shallow (less than 25 m) marine or intertidal waters but eunicid polychaetes are still quite common in deeper waters (Benham 1896).

IVF2 Spirorbids

Tubes of *Spirorbis caperatus* M'Coy, *Spirorbis ambiguus* Fleming and *Spirorbis spinosa* (de Koninck) have been found in the Skateraw Upper Limestone and in washed residues from the mudstone at Dunbar Works. *S. caperatus* has been found in washed residues from Skateraw and indeterminate spirorbids have been found at Cateraig. Previous records of spirorbid worms from the mudstone are *S. caperatus* at Cateraig and Skateraw, *S. ambiguus* at Skateraw, *S. spinosa* at Cateraig, Skateraw and Burlage Quarries and *Spirorbis* sp. at Skateraw (Etheridge 1880, Clough et al 1910).

The tubes are found encrusting crinoid plates and columnals, corals, brachiopods and fenestellid fragments and in some cases at least are post-mortal encrustations since they have been found on internal or articular surfaces.

IVF3 'Vermilia' sp.

Small compressed calcareous ribbon-like tubes identical to those described by Etheridge (1880) as *Vermilia* sp. have been found on columnals in the mudstone at all three localities and in the Skateraw Upper Limestone at Dunbar Works. Specimens in washed residues from the mudstone at Dunbar Works have also been found encrusting fenestellid fragments. The species has been recorded from Skateraw by Etheridge (1880) and Clough et al (1910). As noted by Etheridge (1880) the assignment of the species to
Vermilia is very doubtful but there seems to be no appropriate genus to which it might be transferred.

IVF4 Myzostomites sp.

Gall-like swellings with a central perforation have been found on columnals from the mudstone and the Skateraw Upper Limestone at Dunbar Works. These are believed to be the result of parasitic infestations by myzostome worms which cause similar structures on modern crinoids (Clark 1921) and are referable to the genus Myzostomites CLARKE.

IVF5 Conchotremata sp.

A very weathered ventral valve of Eomarginifera longispina collected from the mudstone at Catcraig (supplementary collection) revealed the existence within the shell of an extensive network of Conchotremata type borings. The diagenetic calcite infill of the borings had weathered out differentially. Conchotremata has been recorded by Lamont (in Reed 1954) in Scottish chonostids and spiriferids and in crinoid crowns.

IVF6 Serpulites carbonarius

Fragments of Serpulites carbonarius M'Coy are fairly common in the upper parts of the Dunbar Works column and small fragments have been found in the Skateraw Upper Limestone of this locality. Three small fragments, one of which was found in the column, have been recorded from Catcraig but the species has not been found at Skateraw.
Some of the tubes found in the Dunbar Works mudstones are extremely long and one possibly complete specimen measuring 150 mm in length was recorded 50 mm below the top of the column.

*S. carbonarius* has recently been redescribed by Wilson (1967) who records that the species is only found in argillaceous rocks. The frequent grouping of fragments together suggested to Wilson (1967) that *S. carbonarius* was a *gregarious* species with a brittle tube.

The biological affinities of *S. carbonarius* are unclear (Wilson 1967) though it has been placed within the Annelida (family uncertain) by Howell (1962). The extremely long thin chitinous tubes with their transverse striae are strikingly similar to, though wider in diameter than, the tubes of modern members of the Pogonophora (Southward and Southward 1967) and it is tentatively suggested that the genus may belong to this phylum. Attempts to elucidate the test structure by clearing in Schultze's solugion have unfortunately not been successful. The only other fossil which has been placed in the Pogonophora is the Cambrian genus *Hyolithellus* (Poulsen 1963).

Recent Pogonophora are *gregarious* and fairly common in organic rich deposits on the continental slope and rise (200 - 4000 m). Shelf species only occur in boreal to arctic waters whose maximum temperature is less than 12°C (Southward and Southward 1967).
**LVF7 Cornulites carbonaria**

*Cornulites carbonaria* (Young) has only been found in the mudstone at Dunbar Works where it occurs most frequently in the middle of the column (610 to 1710 mm). Though isolated specimens occur the species is usually found in small gregarious clusters.

None of the Dunbar specimens appears to have been attached to any object though a small apical portion with a grooved attachment scar has been found in a washed residue. Indeed where apices can be clearly observed they are always found to have been broken and the same feature has been recorded in other cornulitid species (Fisher 1962) though it is not clear whether it is a pre-mortal or post-mortal phenomenon.

Individual specimens may measure more than 15 mm in length and up to 3 mm in diameter which is much larger than the dimensions given by Young (1873). However both Young (1873) and Etheridge (1880), who records the species from Skateraw, based their descriptions on specimens from washed residues which appear to have represented only the adapical portions of the test.

**IVF3 Conodonts**

Conodont fragments have been observed in washed residues from all three localities and a compound bar-like conodont was observed on a hand specimen from the basal shale part of the Catcraig sequence. No attempt has been made to identify these specimens or to include this
group within the study. Several species of conodont have been recorded from the mudstone by Clarke (1953, 1960).
IVG) Phylum Arthropoda

IVG1 Dithryocaris sp.

Mandibles of *Dithryocaris* sp. have been found in all three columns but are most common at Catcraig. They have also been found in the Skateraw Upper Limestone at Catcraig and Dunbar Works. Two very dubious carapace fragments have been found at Dunbar Works (supplementary collection).

Dithryocarid crustacean mandibles, which are superficially similar to and have been described as fish teeth (Skeels 1962) are parts of paired - left and right - appendages. The ratio of left to right mandibles at the three different localities varies considerably (table 6). At Dunbar Works the ratio conforms to the natural one to one ratio but at Catcraig right mandibles predominate and at Skateraw left mandibles are more common. The overall ratio for the area is close to the one to one expected proportion. This is interpreted as the result of sorting by current activity similar to the left-right phenomenon found in bivalves (Lever 1958). The direction of the current is uncertain. Jones and Woodward (1888) have observed that mandibles and carapace fragments are rarely found together and the possible occurrence of such a situation at Dunbar Works together with the mandible proportions at that locality suggest that it may have been the source area for the dithryocarid mandibles.

IVG2 Ostracod spp.

Ostracod tests and valves have been found on hand specimens from all three localities. Several species are present and one, of which
only three specimens have been recorded, attains a size of 3 mm.
No species have however been identified as this essentially microfossil
group has been excluded from the present study.

IVG3  *Weberides mucronatus*

*Weberides mucronatus* (N'Coy) is one of the characteristic species
of the mudstone at all three localities though it becomes less frequent
towards the top of the Dunbar Works column and towards the base of the
Skateraw column. Most occurrences are as isolated pygidia or cephalic
fragments though hypostomes and thoracic segments have also been found.
Two enrolled individuals have been found at Dunbar Works (supplementary
collections).

The overall ratio of glabellae to pygidia is slightly smaller
than one at all three localities (table 7). The ratio varies apparently
without trend at different levels in each column (table 7). The overall
pattern may be the result of current sorting as in *Dithcyocaris* sp.
(section IVG2), differential breakage of weaker pygidia or of collecting
bias due to the smooth glabellae being less easily visible than the
segmented pygidia.

The way-up attitude of glabellae and pygidia is also tabulated
in table 7. The ratio of concave up to convex up pygidia or glabellae
varies at different levels in the columns but again there is no obvious
trend in any column. At Dunbar Works there is a slight tendency
for both glabellae and pygidia to be concave-up and this is also observed
at Catcraig (table 7). At Skateraw however there is an almost consistent
tendency for them to be convex-up. The hydrodynamically stable position
for concavo-convex objects is normally convex-up and thus current activity
at Skateraw may be stronger than at the other two localities. The
fact that Skateraw has the smallest ratio of glabellae to Pygidia may be
linked with this current activity but there seems no reason to suppose
that *W. mucronatus* did not form part of the fauna at each locality.

Since *Weberides* grew by moulting the actual abundance of the species
must be exaggerated by the presence of ecdysal fragments.

**IVG4 Trilobite sp**

The free cheek and two pygidial fragments of an indeterminate
trilobite species have been found on hand specimens collected from the
basel 2 m of the Dunbar Works succession. All carry a marked ornament
of close set tubercles the apices of which are pointed and slightly
hooked.

**IVH Phylum Brachiopoda**

**IVH1 Eomarginifera longispina**

Shells, valves or fragments of *Eomarginifera longispina* (J. Sowerby)
occur in nearly every level of the mudstone at all three localities and the
species has been recorded from Oxwell Mains by Clough et al (1910) and as
*Productus setosus* (see below) from East Barns and Skateraw by Muirwood
(1928).
The specimens referred to in this species form a distinctive and coherent group but due to unrecognised ontogenetic, biometric and diagenetic variation its nomenclature has become veritable Gordian Knot. Ferguson (1960) who recorded this species in the Second Abden Shale near Kirkcaldy, has discussed these problems at length. He recognised that his specimens had been generally affected by compaction and that there were complete series from undistorted to variously distorted end members. After study of type material he concluded that several species belonging to the 'Productus longispinus' group (Muirwood 1928) could be identified with members of his diagenetic variant series and therefore united the following species within the single species Eomarginifera longispina (J. Sowerby) - Productus productus (Martin), P. concinnus (J. Sowerby), Marginicinctus projectus (Muirwood), Alifera minuta (Muirwood), Eomarginifera longispina (J. Sowerby), E. praecursus (Muirwood), E. lobata (J. Sowerby), E. lobata var laqueatus (Muirwood), E. lobata var flexa (Muirwood), E. setosa (Phillips), E. tissingtonensis (Sibly), E. pseudolobata (Muirwood). (Generic designations are as in Muirwood and Cooper 1965). Dunbar specimens of Eomarginifera longispina are affected by compaction and many of the features recorded by Ferguson (1960) can be recognised and, though the inclusion of P. productus, P. concinnus and M. projectus is here rejected (features of the visceral disc or of the dorsal valve seem incompatible with E. longispina), the remainder of his conclusions are accepted and endorsed.

A feature of the second Abden Shale is that though E. longispina was extremely common at several levels all the specimens recorded were
mature enough to have formed trails (juvenile productoids recorded by Ferguson (1960) are in fact the small chonetid *Tornquistia polita*), and this is a feature of other productoid bearing horizons (e.g. the shales below the Coral Limestone, Campsie (MacDonald 1966)). A small productoid, *Etheridorina complectens* (Etheridge), which was adherent on crinoid columnals and bryozoa occurs in washed residues from the mudstone at Dunbar Works and Skateraw and was first described by Etheridge (1876) using material from Skateraw. The specimens referred to *E. complectens* appear to fall into two types, though it is difficult to differentiate between small specimens and though larger specimens are usually fragmentary, it is believed that these types represent the juvenile growth stages of *Eomarginifera longispina* and of *Buxtonia scabricula* (see section IVH). It is not clear whether Etheridge (1876) based his descriptions on one or both of these types (he did consider that *E. complectens* might be the juvenile form of *E. longispina*) but it would seem likely that *E. complectens* should be considered at least in part as a junior synonym of *E. longispina*. The reasons for this association are (i) consideration of size relationships and growth curve (see below). (ii) the ornament of some *E. complectens* consists of rugae and costae like that on the visceral disc of *E. longispina*. (iii) the central umbo of some specimens of *E. longispina* still shows a grooved attachment scar (fig 16).

Though the juvenile stages of *E. longispina* were attached to their host by clasping spines initial attachment was probably by a pedicle and a small supra-apical pedicle sheath has been observed on specimens. Etheridge (1876) observed instances in which the host crinoid had overgrown
and engulfed the productid and similar cases involving both crinoids and bryozoa have been found in the Dunbar Works material.

Trail-bearing specimens of *E. longispina* show a wide variation in length of the median costa relative to the width of the hinge but generally plot within the same field as the Second Abden material (Ferguson 1960) (fig 17). This field is elongated in a manner suggestive of a growth line but the trail of most specimens appears to be damaged and consideration of this factor combined with consideration of the probable growth history of the species leads to a rather different conclusion. Shell growth can be modelled in terms of four parameters (Raup and Michelson 1965) but since in the ventral valve of *Eomarginifera* there is no *w*°r°l* translation and since the axis of coiling is coincident with the hinge only two parameters - rate of expansion and shape of the generating curve - need be considered. During the early growth and formation of the visceral disc the rate of expansion must be high since in a few degrees of rotation the area of the generating curve increases several fold. Judging from the outline of rugae on the visceral disc of *Eomarginifera* the shape of the generating curve changes during this time and growth parallel to the hinge decreases relative to growth at right angles to the hinge. After geniculation and during trail formation growth parallel to the hinge ceases though growth at right angles continues to some extent and thus, since change in area for a given amount of coiling is small during this phase, the rate of expansion must approach close to the theoretical minimum value of one.
When this growth model for an individual is expanded to a variable population a hypothetical growth field can be produced in terms of hinge width and length of the median costa and this field can be subdivided into several areas (fig 18). The juvenile etheridgiform stages will plot in an expanding triangular field (fig 18) and the adolescent trail forming stages will plot in a trapezoidal field whose parallel sides are parallel with the length of median costa axis. The adolescent field will terminate in an elongate adult field. During growth the productoid shell is thin and the scarcity of intact etheridgiform shells is probably related to this feature. In the adult however a degree of robustness is conferred by secondary thickening and by the development of a diaphragm. The outer extremities of the trail are however not protected and where breakage occurs it can usually be seen to have taken place close to the diaphragm. The position of the diaphragm on the median costa will vary with size of the individual and will plot as an elongate field across the adolescent field (fig 18). The apparent linearity of the bivariate plots is therefore interpreted as the result of modification of the adolescent field due to trail breakage giving a tendency for valves to cluster close to the structural field of diaphragm positions.

Though the absence of juveniles from the Second Abden shale and elsewhere may be explained by the above phenomena consideration of the probable life history of *Eomarginifera* suggests another possible mechanism. As already indicated the earliest stages of growth are attached initially by a pedicle and subsequently by inflexible spines. The spat will remain
attached to its host until the weight of the growing shell or some natural accident breaks it free and allows it to sink to the sediment surface. Though the shell shape is such that it will tend to fall on its pedicle valve this transition would appear to be a very hazardous event. However at this stage in life the productoids had a gently concavo-convex shell and it is possible that by repeatedly snapping the shell they may have been able to execute swimming motions. In such a case it is possible that they may have been able to swim short distances near the bottom and find more suitable adult habitats.

Bivariate plots of well preserved dorsal valves show a marked linearity (fig 19) and since dorsal valves do not show the same marked geniculation and trail formation as ventral valves this is interpreted as a growth line. Small etheridggíiform dorsal valves appear to plot on the same line (fig 19). Due to the difficulty of distinguishing between the juveniles of Eomarginifera and those of Buxtonia it has been impossible to obtain a satisfactory series illustrating the ontogenetic development of the cardinal process which is bifid in Etheridginí and trifid in Eomarginifera.

Six long halteroid spines are developed on the ventral valve of Eomarginifera and the presence of these on a specimen is considered a strong indication that it is in an original life position (Shiells and Penn 1971). Specimens from Dunbar Works have been found with a single long spine still attached but it is not thought that any of the specimens of Eomarginifera are in a life position.

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The azimuthal and way-up orientation distributions for the Dunbar Works and Catcraig columns are tabulated in tables 8 and 9. Orientation data from Skateraw where most records are of large valve fragments are too small to be reliable. This may indicate that the Skateraw environment was more turbulent than the other two localities and the higher proportion of convex up specimens at Catcraig may indicate a higher energy environment there than at Dunbar Works.

The azimuthal orientation distributions at both localities are multimodal (tables 8 and 9). The concave-up shells at Dunbar Works exhibit a strong ESE mode and minor NNE and SSW modes. Concave-up shells will probably turn and transport with their umbones (i.e. centre of gravity) directed upstream (Brenchley and Newall 1970) and the Dunbar Works orientation therefore suggests a current derived from the ESE. The minor modes may indicate shells lying transverse to the current or the existence of cross currents. The distribution of convex-up shells is markedly different from that of concave-up shells. The ESE line is a minimum value, is flanked by prominent modes and may have a diffuse WNW counter mode. It is thought that this trimodal system can be produced in the following manner - when the concave up productid shells are overturned they may either flip over and come to rest with their umbones pointing downstream or they may roll on their trail as they turn and come to rest with their umbones pointing upstream but at an angle to the current. A second trimodal system symmetrical about a NNE - SSW line and suggesting a current from the SSW occurs in the convex-up distribution (table 8). This system is in fact better developed than that of the ESE.
current and may indicate that this has been the stronger current. The Catcraig distributions are less easy to categorise though some indication of similar modes can be discerned. In this higher energy environment the two currents may have interfered with each other's orientations more strongly.

IVH2 *Eomarginifera longispina* var.

A variety of *Eomarginifera longispina* with degenerate costae has been found in the mudstone and Skateraw Upper Limestone at Dunbar Works. In the column it was most frequent in the uppermost 300 mm.

The presence of major spine bases shows that the lack of ornament is not due to abrasion. In the absence of costation the major growth lines are prominent.

IVH3 *Buxtonia scabricula*

Fragments and poorly preserved shells of *Buxtonia scabricula* (J. Sowerby) are common in the Dunbar Works column and in parts of the Skateraw column but have never been recorded from Catcraig.

This species never seems to have developed extensive secondary thickenings or diaphragms and was as a consequence highly susceptible to damage.

Some of the juvenile productids of *Etheridgina complектens* type have been referred to this species on the basis of their similar
ornament of small spines. Etheridgina has previously been tentatively associated with Buontonia on the basis of its ornament and of the internal structure of the dorsal valve by Muirwood and Cooper (1965).

IVH4 Fimbriaria sp.

A single shell of a spines lamelllose productid species has been found in the Skateraw Upper Limestone at Dunbar Works. Though the internal characters are not known the ornament of broad lamelllose bands each bearing a short stout spine indicate that it must be referred to the genus Fimbriaria.

This appears to be the first record of the genus outside the Americas and is also the geologically oldest record for the genus which has previously been recorded from late Pennsylvanian and Permian rocks (Muirwood and Cooper 1965).

IVH5 Antiquatonia sulcatus

Three specimens of Antiquatonia sulcatus (J. Sowerby) have been found in the mudstone at Dunbar Works and another has been found at Skateraw. In each case the shell has been compacted and only the ventral valve is visible and all specimens have well developed trails. One specimen bears long (35 mm +), thick (1 mm) spines and may therefore be in a life position (Shiells and Penn 1971). Detached spines of similar thickness have been found on hand specimens from Dunbar Works.
A single flattened shell of *Antiquatonia hindi* (Muirwood) has been collected from the Skateraw Upper Limestone at Dunbar Works.

A single specimen of a moderate sized *Productoid* of unknown genus has been recorded from the mudstone at Dunbar Works. The shell has been badly compacted but the hinge width is estimated to be 23 mm. The shell surface is unornamented except for faint traces of growth lines and for widely spaced spines (0.2 mm diam). These spines are arranged in five series radiating from the umbo. Six millimetres of one of these spines is associated with the shell.

A fragment of an indeterminate *Productoid* characterised by large numbers on long (9 mm) spines and strong costae has been collected from the mudstone at Dunbar Works.

*Avonia aculeatus* (Martin) occurs at several levels in the Dunbar Works and Skateraw columns but has not been recorded from Catcraig. Specimens often appear fragmentary but this is difficult to determine since the shells usually exfoliate upon extraction.

A brachial valve fragment found in a washed residue from the mudstone at Dunbar Works reveals that this species has a small bifid cardinal
process resting a low median septum which extends slightly more than a third of the valve length. The adductor muscle scars are prominent and about half as long as the median septum but the brachial ridges are inconspicuous. Anteriorly the internal surface of the valve is ornamented with short spines.

**IVH10  Echinocochus punctatus**

_Echinocochus punctatus_ (J. Sowerby) is a characteristic species of the upper 120 mm of the Dunbar Works column. The species is also common in the Skateraw Upper Limestone at Dunbar Works.

The large shells or ventral valves are usually markedly affected by compaction and in most cases their status as shell or valve is impossible to determine. Disarticulation of shells has however occurred since dorsal valves have been recorded. The amount of orientation data available is small (table 10) but the concave-up shells (or valves) show a slight ESE orientation trend.

A medium sized dorsal valve collected from the Skateraw Upper Limestone showed an interesting pathological condition. The left hand margin of the valve carried a deep triangular embayment. The concentric banding of the shell though truncated by the notch appeared to be slightly deflected close to the notch margins which were raised internally in a rim. The feature appears to be the consequence of damage to and necrosis of part of the mantle edge while the animal was a juvenile. During subsequent growth as the mantle edge expanded this necrotic zone
also increased in size leaving an ever increasing non-calcified wedge in the shell behind it.

IVH11  *Fluctuaria undatus*

Fragments of a thin shelled producted with fine costellae and wide rugae have been found in the column at Dunbar Works and one fragment was observed in the Skateraw column. No specimens have been recorded from the mudstone at Catorraig or from the Skateraw Upper Limestone.

The rugae may be a compactional feature though they have a consistent orientation normal to the costellae. Though the shape of the shell and hinge and umbonal characters are unknown the species may possibly be referred to *Fluctuaria undatus* (Defrance).

The poor preservation of this species may like that of *Buxtonia scabricula* (see section IVH3) be due to the thinness of the shell and the apparent absence of secondary thickening such as in *E. longispina* (W.H.I.).

IVH12  *Cleiothyridina sublamellosa*

*Cleiothyridina sublamellosa* (Hall) is a characteristic species of the upper parts of the Dunbar Works column (0 - 860 mm) but is less frequent in the middle of the column (860 - 3030 mm) and is absent at the base. *C. sublamellosa* is also extremely common in the Skateraw Upper Limestone at Dunbar Works. Only single specimens have been recorded from the Catorraig and Skateraw columns and both occurred towards the top of the local succession.
This species has been recorded from the mudstone as *Cleiothyris roissyi* (= *Cleiothyridina deroissyi* (Lévillé)) by Clough et al. (1910). *C. deroissyi* is a poorly defined species, Davidson (1862) but the original description (Lévillé 1835) clearly indicates the existence of a fold and sinus which is not present in the Dunbar species. Specimens identical to those from Dunbar have been found at Invertiel and Carlylops and have been described and figured by Reed (1954) as *Cleiothyridina sublamellosa*. This placement is accepted here though due to compaction effects one of the specific characters the relative convexity of the valves cannot be fully evaluated.

The valves are invested with conspicuous ornament of spiny frills. The spines are solid and cannot themselves have had a sensory function though the peripheral frills could have formed a protective grill through which setae may have projected or by which large sediment particles were excluded. Secondarily the frills may have served to stabilise the shell in a soft substrate in a manner similar to that postulated for *Acanthothyris* (Rodwick 1965).

Azimuthal and way-up orientation distribution data is given in table 11. Concave-up valves are more common than convex-up valves and as this is probably the mechanically less stable position may indicate that currents were not strong. The concave valves show a trimodal distribution with modes in NE, SSW and WNW positions. Concave-up shells might be expected to orientate with their umbones (i.e. centre of gravity) upstream and in *C. sublamellosa* this would also be the most
streamlined position with respect to the spiny frills. These frills would however resist movement across the mud surface and as a result valves might tend to flip over or to swing across the current or with their umbones downstream. Valves across the current and with their umbones downstream would appear to be at a disadvantage on both centre of gravity and streamlining criteria and will thus move into another position or be overturned. The distribution which is symmetrical about an ESE - WNW line may thus indicate an ESE current. The orientation of convex-up valves is diffuse as might be expected from the overturning and lateral rolling of valves with a variety of initial orientations (see also below).

Shells with their ventral valve uppermost are less common than those which are dorsal valve up but it is not clear which is the mechanically more stable position. Shells which are ventral valve up have orientation distributions which are symmetrical about a SSW - NNE line and the major modes are to the south-east and west. Shells which are dorsal valve up are also generally symmetrically orientated about a SW - NE though here there is only single wide NE mode. Taken together the two distributions suggest a trimodal orientation to a SW or SSW current and the difference between the two orientations may reflect the influence of slight differences in the convexity of the dorsal and ventral valves.

The different current directions inferred from the orientation of shells and valves may reflect the differing relative strengths of these currents. A weaker but probably more persistent ESE current is capable of orientating valves but has only a limited affect on shells
(a slight downstream mode is visible on the orientation distribution pattern of dorsal valve-up shells) while a stronger less persistent SW or SSW current is capable of orientating shells (and valves). The diffuseness of the convex-up valve orientations may be partially due to the action of this current.

IVH13 Composita ambiguа

Specimens of Compositа ambiguа (J. Sowerby) have been recorded from the upper parts of all three columns and in the Skateraw Upper Limestone at Dunbar Works and Catcraig. Most records are of fragments and where valves or shells have been found they are usually flattened by compaction. Shells have not been recorded from Catcraig or Skateraw.

IVH14 Crurithyris urei

Specimens of Crurithyris urei (Fleming) are common in the columns of all three localities though the frequency of occurrences at Dunbar Works decreases towards the top of the succession. It has not been recorded from the Skateraw Upper Limestone.

Specimens of C. urei are generally small (maximum size = 6 mm) and the majority of individuals are close to or in the vague boundary zone (see IVA) between micro- and macro-fossils. In addition the adherence of clay particles to the finely sphinose valves and shells may make them difficult to distinguish from mudstone fragments. Many specimens were noted only after they had been disturbed and their orientation lost. Strong reservations must therefore be admitted as to how representative the collection data are of the fossil population.
C. urei is a characteristic fossil of parts of the Second Abden Shale, near Kirkcaldy, where it attains a maximum size of 10 mm and can clearly be regarded as a macrofossil (Ferguson 1960). The size difference between the Dunbar and Second Abden material may be indicative of stunting. This hypothesis seems difficult to reconcile with the abundance of the species and with the lack of evidence for stunting in *Eomarginifera longispina* which is a characteristic associate at both Dunbar and Kirkcaldy. Abundance might however be exaggerated by a rapid turnover of short-lived populations.

Compaction effects similar to those documented by Ferguson (1960, 1962) have been found though most shells and valves are orientated parallel to the bedding. The way-up orientation of shells and valves at different levels in the columns is summarised in table 12. In both dorsal and ventral valve distributions the overall ratio of concave-up valves to convex-up valves is greatest at Dunbar Works and least at Skateraw though the differences especially in the ventral valve ratios are small. The concave-up position is mechanically less stable than the convex-up position so this may indicate a decreasing energy of the environment in the series Skateraw - Catcraig - Dunbar Works. The disparate ratio of dorsal to ventral valves probably reflects collecting bias since these flat valves may be more easily missed than ventral valves or shells. The overall ratio of ventral-up shells to dorsal-up shells is greatest at Dunbar Works and least at Skateraw. This may indicate that the ventral-up position is less stable mechanically.
Specimens of *Dielasma aff gillingense* (Davidson) have been found in all three columns but have not been recorded from the Skateraw Upper Limestone.

Shells of *D. aff gillingense* are almost always filled with finely granular pyrite and as a result when exposed to weathering or to extraction techniques the rapid deterioration of the pyrite causes destruction of the shell. This phenomenon makes it difficult to determine the characters of the species. A marginal sinus has not been recognised and if present must be extremely weak. Two species of *Dielasma* with a weak sinus have been recorded - *Dielasma hastatum* (J. Sowerby), var *amygdaloideas* de Koninck (Reed 1954) and *Dielasma gillingense* (Davidson) (Davidson 1862). Judging from illustrations given by Reed (1954) and Davidson (1862) the marginal sinus of *D. gillingense* is less well developed than that of *D. hastatum* var *amygdaloideas* and the Dunbar species has therefore been associated with *D. gillingense*. The status of *D. gillingense* is however rather unsatisfactory. Davidson (1862) both described it as a new species and regarded it as a variant of *D. hastatum* (J. Sowerby). The Dunbar species is smaller (maximum size 8 mm) than either *D. gillingense* (19 mm maximum - Davidson 1862) or *D. hastatum* var *amygdaloideas* (12 mm maximum - Reed 1954).

The presence of the pyrite is regarded as the result of decay of the body within the shell.
**IVH16 Pleuropugnoides pleurodon**

Though rare towards the top of the Dunbar Works column shell fragments of *Pleuropugnoides pleurodon* (Phillips) are otherwise common in all three columns. Intact shells and valves are extremely rare and are always badly affected by compaction. *P. pleurodon* has also been recorded from the Skateraw Upper Limestone.

During extraction specimens of *P. pleurodon* tend to fragment but can be easily recognised by the characteristic silky lustre of the fracture surfaces. This results from the finely fibrous or prismatic structure of the shell.

**IVH17 Hustedia radialis**

Two shells of *Hustedia radialis* (Phillips) have been recorded from the Dunbar Works column. The species has not been recorded from either of the other localities or from the Skateraw Upper Limestone.

**IVH18 Rhipidomella michelini**

Specimens of *Rhipidomella michelini* (L'Éveillé) are found at several levels throughout the Dunbar Works column but are rare in the Catcraig column. In the Skateraw column specimens have been recorded in two distinct groups of levels: 230 to 360 mm and 810 to 900 mm. The species also occurs in the Skateraw Upper Limestone at Dunbar Works.

Most records are of small shells about 4 to 6 mm in height but the largest shells are considerably larger (Dunbar Works - 11.5 mm, Skateraw - 11.2 mm, Catcraig - 14.4; supplementary collections). The species reaches
an even larger size in the Skateraw Upper Limestone where the maximum height of shell is 21.5 mm. The shells are normally found lying parallel to the bedding and have been compacted. The reduction in thickness is accomplished by a typical radial and concentric cracking of the valves.

IVH19 Schizophoria resupinata

A single large ventral valve of Schizophoria resupinata (Martin) has been recorded from the mudstone at Dunbar Works (supplementary collection).

IVH20 Phricodothyris lineata

Shell fragments of Phricodothyris lineata (Martin) have been found in the Dunbar Works column and are most frequent in the upper central parts of the sequence (810 - 1320 mm). Rare fragments have been found towards the top of the Skateraw and Catcraig columns. P. lineata has not been recorded from the Skateraw Upper Limestone.

No intact shells or valves of this species have been found and identification must therefore be tentative. The shell ornament of double-barrelled spine bases arranged along concentric growth lines suggests that the species concerned may be P. lineata.

IVH21 Tylothyris peracuta

A single shell of Tylothyris peracuta (Reed) has been found in the Skateraw Upper Limestone at Dunbar Works.
Shells and valves of *Tylothyris fifensis* (Reed) occur occasionally in the Dunbar Works column but the only records from the Catcraig and Skateraw columns are of valve fragments. The species is also common in the Skateraw Upper Limestone at Dunbar Works.

A single shell of *Brachythyrina bisulcatus* var *roscobiensis* (J. Sowerby) var *roscobiensis* (Reed) has been found in the Dunbar Works column. The species has not been recorded from Skateraw or Catcraig. A few specimens have been collected from the Skateraw Upper Limestone at Dunbar Works.

Specimens of *Schuchertella fascifera* (Tornquist) have been recorded from the top of the Dunbar Works column and from the base of the Catcraig and Skateraw columns. A single dorsal valve has been found in the Skateraw Upper Limestone at Dunbar Works.

*Schellwienella radialis* var *decorata* (Phillips) var *decorata* (Reed) has only been recorded from the Skateraw Upper Limestone at Dunbar Works in which it is rare. This is one of the largest brachiopods in the fauna, the largest specimen having a height of 53 mm and a width of 63 mm.
A single specimen of *Pliochonetes* sp. was recorded near the base of the Skateraw column. The species was not recorded in either of the other two columns though a specimen has been found in the mudstone at Dunbar Works (supplementary collection). Eighteen specimens of *Pliochonetes* sp. have been found in the Skateraw Upper Limestone at Dunbar Works.

This is the first record of this genus in the Lower Limestone Group of Scotland. Previously only four specimens of a *Pliochonetes* sp. were known from the Upper Limestone Group (Brand 1970). The Dunbar specimens are apparently identical to this material as described by Brand (1970) though there may be a slightly larger number of ribs in the Dunbar shells. Unfortunately despite the considerably larger amount of material from Dunbar little can be added to Brand's (1970) description, except to note that a median septum occurs in the ventral valve.

*Rugosochonetes celticus*

*Rugosochonetes celticus* MuirWood pars occurs occasionally in the column at Dunbar Works. It has not been found in either of the other two columns though specimens have been found at these localities. The species has been found in the Skateraw Upper Limestone at Dunbar Works.

The Dunbar material agrees with the recent redescription of *R. celticus* by Brand (1970) though there is a notable size difference. The maximum shell width at Dunbar lies low in the width range recorded
by Brand (1970) (5.0 - 26.6 mm), (see also R. speciosus, IVH28).

IVH28 Rugosochonetes speciosus

A single specimen of Rugosochonetes speciosus (Cope) has been found in the lower parts of the Catercraig column. The species is known to occur in the mudstone at both of the other localities (supplementary collections). R. speciosus is also found in the Skateraw Upper Limestone at Dunbar Works.

The Dunbar specimens agree with the recent redescriptions of R. speciosus by Brand (1970) though as in R. celticus (IVH27) there is a size difference. The shell width in specimens examined varies from 8 mm to 29 mm though only three specimens with widths less than 20 mm have been found. The Dunbar material thus tends to be rather larger than the size indicated by Brand (1970) (6.3 - 23.0 mm). R. celticus and R. speciosus have been confused in the past (Muirhead 1962) and the size ranges of the two groups might suggest that they should be considered as one species. However the internal characters which are as described by Brand (1970) and the greater convexity of the ventral valve in R. celticus clearly indicate that two species are present. The reasons for these size distributions are not known.

IVH29 Tornquistia polita

The small chonetid Tornquistia polita (M'Coy) has been found in every level of the Catercraig and Skateraw columns. In the Dunbar Works
column T. polita is infrequent in the upper 540 mm but below that is almost ubiquitous. T. polita has also been recorded from the Skateraw Upper Limestone of all three localities.

Like Crurithyris urei (see IVH14) T. polita is a small species and, though large specimens may attain a hinge width of 6 mm, most specimens are less than 4 mm wide. Due to this small size reservations must be expressed as to the extent to which the data represents the fossil population.

The most difficult valve to detect is the dorsal valve which is flat and similar to a mudstone fragment. Shells and ventral valves are more easily spotted but due to the fact that compaction effects are accommodated by collapse of the dorsal valve into the body chamber without apparent distortion of the ventral valve it is often very difficult to distinguish between shells and ventral valves.

The way-up distribution of shells and ventral valves is tabulated in table 13. The overall ratio of concave-up to convex-up shells and valves is greatest at Dunbar Works and least at Skateraw and since the concave-up position is probably less stable this may indicate decreasing energy of environment in the sequence Skateraw - Catcraig - Dunbar Works. Within each column there is little sign of any trend in ratios except at the top of the Skateraw column where convex-up shells become more frequent. This suggests an increasingly energetic environment during the formation of these layers. At Dunbar Works a slight trend to increased energy may be indicated between 3270 and 1750 mm.
Specimens referable to *T. aff polita* and *T. cf polita* as defined by Brand (1970) occur in the shale but there appears to be a complete passage from these to *T. polita* and no separation has been made.

**IVH30 Tornquistia youngi**

*Tornquistia youngi* (Wilson) occurs in the upper half of the Catcraig and Skateraw columns. It has not been found at Dunbar Works either in the mudstone or in the Skateraw Upper Limestone.

Most of the specimens in both Catcraig and Skateraw columns are fragmentary and therefore orientation data is not available.

**IVH31 Tornquistia? subminima**

A single shell of the small species *Tornquistia? subminima* (M'Coy) has been found in the Skateraw Upper Limestone at Dunbar Works.

**IVH32 Crania ryckholtiana**

The species *Crania ryckholtiana* (de Koninck), to which most specimens previously labelled *C. quadrata* (M'Coy) have recently been transferred (Graham 1970) has been observed at all three localities but has only been recorded in the Catcraig and Skateraw columns. *C. ryckholtiana* is also known from the Skateraw Upper Limestone at Dunbar Works.
At Dunbar *C. ryckholtiana* has only been found attached to columnals or orthocone fragments, though Graham (1970) has figured specimens adherent on brachiopod shells. Columnals and orthocones will probably provide a smooth sediment free surface for cementation without too much distortion of the brachiopod's shell.

**IVH33 Orbiculoidea cincta**

*Orbiculoidea cincta* (Portlock) has been found at several horizons in the Dunbar Works column. The species has also been recorded from the Skateraw Upper Limestone at Dunbar Works and from the mudstone at Catcraig (supplementary collection).

Graham (1971) has recently revised the nomenclature of Scottish *Orbiculoidea* and has shown that most specimens formerly ascribed to *O. nitida* should be placed in *O. cincta*.

Most specimens of *Orbiculoidea* found have been loose shells or valves. In some cases however *Orbiculoidea* shells have been found squashed on to crinoid columnals or orthocone fragments. As with *C. ryckholtiana* (*IVH32*) these would seem to form an excellent substrate. Apparently adherent shells may thus be preserved in their life position even though they are not necessarily in their original life orientation.

**IVH34 Lingula mytiloides**

*Lingula mytiloides* (J. Sowerby) has been recorded in all three columns and is also found in the Skateraw Upper Limestone at Catcraig and Dunbar Works.
Most specimens are of shells or valves lying in the bedding plane. Two specimens have been found highly inclined to the bedding. One from Dunbar Works was orientated umbones up but the other from the Skateraw Upper Limestone of Catcraig had its umbones directed down and might tentatively be regarded as being in a life position.

IVH35 Brachiopod Ecology

The high diversity of the brachiopod fauna of the mudstone and Skateraw Upper Limestone and in particular the high diversity of these beds at Dunbar Works indicates that conditions were particularly favourable for brachiopods. Brachiopods are low level suspension feeders and the bottom waters may thus have been rich in minute suspended food particles.

An abundance of fossil brachiopods may be taken as indicative of shallow fully marine conditions (Rudwick 1970) but it seems unlikely that the modern predominantly temperate distribution of brachiopods existed in the past (Rudwick 1970). The presence of Lingula which is often thought of as a brackish water species is not necessarily inconsistent with a normal marine salinity. Quite apart from the possibility that the shells and valves of L. mytiloides may have been transported into the area it appears that at present lingulides are essentially marine animals capable of tolerating reduced salinity (Craig 1952). Though most abundant in the upper 20 m modern lingulides can occur in depths of just over 100m (Craig 1952). In the Scottish Carboniferous the characteristic species of the presumed brackish water
Lingula bands which contain few other brachiopod species is *L. squamiformis* (Graham 1970) and it would appear that *L. mytiloides* was a more stenohaline species.

Stevens (1971) has found that in a shallow marine Pennsylvanian environment the diversity of brachiopods increased with depth to a maximum at about 20 m (the limit of his study). Though *Antiquatonia* and *Composita* and a spiriferid were found in very shallow depths *Cleiothyridina* was only found at localities believed to have been deeper than 7 m. and *Echinoconchus* in localities deeper than 11 m. These figures may thus give some indication of the upper limit of the probable depth of deposition of the mudstone.

Colonisation of muddy surfaces may pose several problems for species. The abundance of mud may smother shells and interfere with feeding. This problem is most serious in juveniles and the adherent stage of the productid life cycle presumably represents one possible solution. Though many of the brachiopod species appear to have been free-lying in adult life their juvenile stages may also have had an attached pedunculate habit. Other species may have been able to attach themselves directly to the substrate with pedicle rootlets like those of *Chlidonophora* (Rudwick 1961). A large number of the Dunbar species have a spinose ornament and this may have served a stabilising and anchoring function though in some cases this was secondary to other roles, e.g. *C. sublamellosa* (IVH 12) and possibly chonetids (Rudwick 1970).
Fragments of *Catastroboceras* spp. are common in the columns of all three localities, and have also been found in the Skateraw Upper Limestone at Dunbar Works. These fragments can rarely be specifically identified but better preserved specimens and intact conchs from the mudstone at Dunbar Works (supplementary collections) reveal the presence of two species - *Catastroboceras quadratum* (Fleming) and *C. broadstonense* Turner.

The co-existence of the two 'species' which differ only in their number of ventral spiral lirae might perhaps be suggestive of sexual dimorphism. However mature conchs of *C. quadratum* from Dunbar Works (supplementary collection) appear to fall into size groupings of 30 and 35 mm diameter which might indicate the presence of sexual dimorphism in this species and thus that the two species are distinct. The mature conchs can be indisputably recognised by the presence of a slightly constricted aperture with hyponomic and ocular sinuses. This feature was not recorded by Turner (1965) in his description of these species but a hyponomic sinus is evident in one of his figures. The body chamber occupies one quarter of the final whorl.

Fragments of *Epidomatoceras neilsoni* Turner have been found in the mudstone at Dunbar Works (supplementary collection). They have not been recorded in any of the columns or from the Skateraw Upper Limestone. Their absence from the columns may be due to confusion with *Catastroboceras*. 

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Coiled cephalopods

Indeterminate fragments of goniatites and coiled nautiloids have been recorded from all three columns but have not been found in the Skateraw Upper Limestone.

Goniatite fragments from Dunbar Works (supplementary collection) have been identified as Sudeticeras newtonense Moore and as Beyrichocerasides truncatus (Phillips). The latter species has also been recorded from Catcraig (supplementary collection). S. newtonense has been recorded from East Barns (Currie 1954) and was taken to indicate a high P2 age.

The nautiloid fragments with one exception are all smooth shelled and indeterminate. A single nautiloid fragment from Dunbar Works carries dorso-lateral carinae suggestive of Biastrialites sp.

Goniatite, coiled nautiloid and other cephalopod fragments are often marked by small irregularly spaced indentations (approx 0.2 mm diameter). These pocks occur on both internal and external surfaces. Similar markings have been observed on recent Nautilus shells which have been exposed to marine influences for a long time and may represent the initial stages of shell decay round slight structural imperfections.

Smooth orthocones

Fragments of smooth orthoceridic shells have been found in all three columns and are found in the Skateraw Upper Limestone at Dunbar Works.
Specimens which have been sectioned have all suffered fracturing of septae and siphuncular tubes during compaction. There appears to have been a complicated sequence of diagenetic infill of chambers by calcite and this has obscured the nature of the cameral and siphuncular deposits. Some specimens may possibly be referred to Pseudorthoceras sp. Specimens whose apices are preserved reveal the presence of at least two species - one with a pointed apex and the other with a blunt apex. In both cases the juvenile stages are slightly cyrtoconic. Fragmentation of the orthocones appears to be initiated by loss of the body chamber and apex ultimately followed by destruction of the remainder of the phragmocone. No completely intact smooth orthocone has been found.

Phragmocone orientations for Dunbar Works and Catcraig are summarised in table 12. Information is not available from Skateraw where the degree of fragmentation is greater and perhaps indicates a more turbulent environment. When considered as a lineation the orthocones have a pattern resembling that produced in crinoid columns (Schwartzacher 1963) and suggest currents with a generally SE - NW or SW - NE lineation. The strong WNW mode at Dunbar Works may indicate a SE - NW current and the apices may point downstream since the orthocones may rotate about their widest diameter which will drag on the mud surface. A minor NE mode at Dunbar Works may also indicate the presence of a SW current.

Other orthocones

Fragments of *Cyrtoceras rugosum* (Fleming) and *Reticycloceras sulcatum* (Ewing) have been found in all three columns and the latter species has
been recorded from the Skateraw Upper Limestone at Dunbar Works. The only intact specimen of either of these species is a badly compacted specimen of C. rugosum from Dunbar Works (supplementary collection).

At least three other species of orthocone have been found at Dunbar Works. The commonest of these, which has been found in the column, is always found as small fragments with a fine transverse striate ornament and has not been identified. The second species of which only three specimens have been found belongs to the genus Kionoceras. The third species is represented by a single very large specimen (0.3m long) in the supplementary collection. The adapertural portions of the shell are flattened by compaction and the apex has been lost. The shell appears to have been curved and had a transverse ribbed ornament but has not been identified. The specimen is heavily encrusted by Distulipora.

IVI6 Cephalopod ecology

Many of our ideas about the ecology of Palaeozoic cephalopods are based on our knowledge of the recent Nautilus. The restricted occurrence of this relict genus however indicates that such extrapolation may involve considerable error and it would seem from their great abundance and diversity that Palaeozoic cephalopods may have occupied habitats and niches similar to those occupied at present by squids, octopi and cuttlefish.

The presence of chambered shells does however indicate the probable existence of a buoyancy mechanism and on death and decay of the animal
these air filled conchs may have floated. House (1973) has shown that
the distribution of dead Nautilus shells is at least twice as great as
that of the live animal and many of the shells in the mudstone may
represent drifted shells. Reyment (1958) has however shown that conch
flotation depends on a number of conch characters and the highly
evolute compressed conchs of Catastrobocteras spp. and Epidomatoceras
neilsconi probably did not float on the death of the animals.

IVJ) Phylum Mollusca - Gastropoda

IVJ1 Introduction

The gastropod molluscs of the shale have presented several problems.
Examination of washed residues from Dunbar Works and to a lesser extent
from Catcraig and Skateraw reveals that there are a large number
of gastropod species present in the mudstone. The bulk of specimens
are however of near microscopic size and thus records of these small
species from the column must be treated with great reservation. The
gastropod species are listed in Table 3 and the levels at which small
specimens were found is given in the enclosures. Several macroscopic
gastropods are also found and are discussed below.

IVJ2 Platyceras neratoides

Occasional specimens of Platyceras neratoides (Phillips) have
been recorded from the Dunbar Works column. The species is also
known from the mudstone at Catcraig and Skateraw (supplementary collections)
and from the Skateraw Upper Limestone at Dunbar Works.
Though no such specimens have been recorded from Dunbar, platycerid gastropods have been widely reported on the tegmen of crinoids with their aperture over the crinoid anus in a manner suggesting a coprophagous habit (Ager 1963, Ubachs 1953, Bowsher 1955). The apertures of Dunbar specimens of *Platyceras* are fairly even and the obvious host would appear to be the common platycrinoid species of the mudstone which have wide flat smooth tegmens. No traces of attachment scars like those described by Ubachs (1953) have been found.

IVJ3 *Straparollus (Euomphalus) carbonarius*

Rare specimens of *Straparollus (Euomphalus) carbonarius* (J. de C. Sowerby) have been recorded from the Catcraig and Dunbar Works columns but the species is more common in the Skateraw column. Specimens are also found in the Skateraw Upper Limestone at Dunbar Works.

As pointed out by Wilson (1966) the abandoned early whorls of the shell which are cut off by septae could contain trapped gases and the increased buoyancy would assist the animal in life on a soft bottom.

IVH4 *Angynomphalus radians*

A single specimen of *Angynomphalus radians* (de Koninck) has been recorded from the shaly base of the mudstone at Skateraw and a second specimen has been found at Dunbar Works (supplementary collection).
IVJ5  *Naticopsis* sp.

Large poorly preserved specimens of *Naticopsis* sp. have been found in the mudstone at Catcraig (supplementary collection). They appear to be not uncommon in the mudstone at this locality but were not recorded in the column.

IVJ6  *Bellerophontidae*

Specimens of bellerophontid gastropods have been found towards the base of the Dunbar Works column and in the upper parts of the Catcraig and Skateraw columns. Preservation is poor as the shells disintegrate into a powder and specific determination cannot normally be made. Such specimens as can be determined combined with information from the supplementary collections show that the following species are present - *Bucaniopsis roscobiensis* Weir, *Bucaniopsis decussatus* (Fleming), *Bucaniopsis tenuis* Weir, *Euphemites urei* (Fleming).

Clough et al (1910) have recorded *Bucania decussata* (Fleming) (= *Bucaniopsis decussatus*), *Euphemus urei* (Fleming) (= *Euphemites urei*) and *Tropidocyclus oldhami* (Portlock) from Skateraw and also record the two former species from Oxwell Mains. *Bucaniopsis decussatus* has been recorded from East Barns by Weir (1931) who also recorded *Tropocyclus oldhami* from Skateraw. *T. oldhami* has not been found in the present study. According to Weir (1931) the stocks of *E. urei*, *B. decussatus*, *B. striatus* and *T. oldhami* attain their acme of profusion at the horizon of the Neilson Shell Bed which is the level at which the mudstones are believed to lie (Section II D).
Carboniferous bellerophonids occur most frequently in argillaceous strata (Weir 1931, Wilson 1966) but this conflicts with habits and anatomy of modern aspidobranchs which are unable to live on soft mud (Craig 1954, Wilson 1966) and it would appear that bellerophonids must have been adapted in some way to cope with muddy environments. Occurrences of B. tenuis are often somewhat different from the norm in that it is found in ribs of ironstone or limestone (Weir 1931). This phenomenon does not occur at Dunbar though B. tenuis has always been found as siderite casts to which small areas of shell still adhere. However a siderite infill also occurs in other bellerophonid specimens in the mudstone and may indicate decay of the body within the shell.

**Palaeozigopleura rugifera**

Palaeozigopleura rugifera (Phillips) occurs fairly frequently in the Catcraig column and is also found in the Skateraw column and at the top of the Dunbar Works column. It is also recorded from the Skateraw Upper Limestone of Dunbar Works in which another zygopleurid, Palaeozigopleura scalaroidea (Phillips) is also found.

**Gastropod Ecology**

The gastropod fauna includes several species typical of this horizon elsewhere in Scotland and the ecology of this fauna has been discussed by Wilson (1966). The wide variation in shell shape suggested to him a diversity of life habits (Wilson 1966) though most forms were probably herbivorous (Knight et al. 1960). No bored shells have been recorded from
the mudstone and it thus seems likely that the Dunbar species were herbivores or deposit feeders. Johnson (1962) suggested that a high incidence of gastropods might indicate the former presence of plants on a soft substratum and the present diversity might thus result from a diversity of niche with respect to feeding on such plant material. Thus some species may have lived on upright algae while others were epifaunal or infaunal bottom dwellers.

IVK) Phylum Mollusca - Bivalvia

IVK1 Polidevicia attenuata

Polidevicia attenuata (Fleming) is common in the Catcraig column and occurs occasionally in the Skateraw column. In the Dunbar Works column it is restricted to a small zone between 790 and 1040 mm. The species has not been recorded from the Skateraw Upper Limestone.

Most records were of valves or fragmented specimens but a number of shells were found at Catcraig. Though very limited the data are tabulated in table 13. The shells found with their valves at right angles to the bedding and with umbones directed up may be in a life position similar to that occupied by the modern elongate nuculid Yoldia (Stanley 1970). Such shells show an orientation which might result from rheotactic orientation to currents from the south west and east. The remaining shells which are orientated with their shells at a high angle to the bedding have their umbones down and are probably not in a life position. Their orientation may indicate a mechanical orientation to similar current directions as also does the orientation of shells whose valves
lie in the plane of the bedding.

The single shell recorded at Skateraw had a posterior direction of 257° and as it was in a 'life position' may have been aligned to a SW current. Two shells lying in the plane of bedding were found at Dunbar Works and their orientations (177° and 308°) may indicate SW and easterly currents.

Shells of *P. attenuata* are usually infilled with siderite which may perhaps indicate decay of the body within the shell.

**IVK2 Nuculana brevirostris**

Apart from two specimens found in the Catcraig column *Nuculana brevirostris* (Phillips) was only found in the Dunbar Works column. A specimen was found at Skateraw during supplementary collecting.

Shells of *N. brevirostris* were only found in the Dunbar Works column and where closed had been infilled with siderite which is perhaps indicative of the decay of the body in the shell. One shell had gaped widely and lay with its valves open and concave up in the plane of the bedding.

**IVK3 Palaeoneilo laevirostrum**

Rare valves of *Palaeoneilo laevirostrum* (Portlock) were found in all three columns.

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P. laevirostrum was only found both in the columns and in supplementary collection as isolated valves and, unlike the other nuculids of the mudstone which have relatively thick shells, these were thinned composite moulds which had a thin brownish surface. This may indicate a different shell structure or composition.

IVK4 Nuculopsis gibbosa

Specimens of Nuculopsis gibbosa (Fleming) have been found at Dunbar Works and at Skateraw (supplementary collections) but were not recorded in the columns.

Closed shells of N. gibbosa usually have a sideritic infill and the body of the animal thus may have decayed within the shell.

IVK5 Cypricardella selysiana

Two valves of Cypricardella selysiana (de Koninck) have been found in the mudstone at Dunbar Works (supplementary collection). The species has not been found at Cat Craig or Skateraw or in the Skateraw Upper Limestone.

IVK6 Cypricardella concentrica

A single squashed shell of Cypricardella concentrica Hind has been recorded from the mudstone at Dunbar Works (supplementary collection).
IVK7 Edmondia sulcata

A single valve and one doubtful specimen of Edmondia sulcata (Fleming) have been found at Dunbar Works (supplementary collection). No specimens have been found at the other localities or in the Skateraw Upper Limestone.

IVK8 Edmondia lyelli

During excavation for the Dunbar Works column several valves and a shell of Edmondia lyelli Hind were found in the uppermost 300 mm of the mudstone. Only one specimen, a single valve, was however found in the column itself. There are no other records of the species in the mudstone or in the Skateraw Upper Limestone.

IVK9 Sanguinolites sp.

Thin shelled valves of a small bivalve have been found towards the top of all three columns. The valves are always crushed and are impossible to recover during extraction. Specimens in the supplementary collections seem to be of sanguinolites type and have an umbal ridge similar to that of Sanguinolites clavatus (Etheridge).

In two levels of the Dunbar Works column left and right valves of identical size were found lying close together.

IVK10 Smooth pectenid

An unornamented pectenid species appears to be common in all three columns but has proved impossible to identify. Specimens which are
isolated valves occur as moulds which appear on hand specimens as smooth circular patches. The valves are always distorted by compaction but the species appears to have been equivalved or almost so. The only ornament observed are a few indistinct growth lines. The characters of the ears are unknown.

It is quite probable that at times this species has been confused with *Euchondria neilsoni* (see section IVKll), the right valve of which is almost unornamented. The concentric filia of the right valve of *E. neilsoni* are however more marked than the growth lines of the present species which also has a more circular outline. The lack of information concerning the ears is unfortunate since those of *E. neilsoni* are ribbed.

IVKll *Euchondria neilsoni*

Left and right valves of *Euchondria neilsoni* Wilson are common in the Catcraig column and to a slightly lesser extent in the Skateraw column but are rare in the Dunbar Works column.

The species is never well preserved and occurs as essentially composite moulds the surfaces of which are separated by a thin grey or brownish shiny film. Some confusion may exist between *E. neilsoni* and an indeterminate pectenid which also occurs in the mudstone (see section IVJ10).
IVK12  *Pernopecten fragilis*

Valves of *Pernopecten fragilis* Wilson have been found in the columns of all three localities.

Like the other pectinids in the mudstone *P. fragilis* is never well preserved.

IVK13  Other pectenids

A number of other pectenid species have been observed at Dunbar Works both in the column and the supplementary collection. These are always poorly preserved and only one species, *Limipecten dissimilis* (Fleming) has been identified. A fragment of *L. dissimilis* has been observed in the Dunbar Works column.

IVK14  Posidonia corrugata

Specimens of *Posidonia corrugata* (Etheridge) and of *Posidonia corrugata* (Etheridge) var *gigantea* Yates occur at all three localities but have not been differentiated during extraction. The species is most common in the Dunbar Works and Catcraig columns and is only recorded at one level in the Skateraw column.

The coexistence of *P. corrugata* and *P. corrugata* var *gigantea* is a characteristic feature of the Neilson Shell Bed (the horizon at which the mudstones lie) but Wilson (1966) doubted if this was related to the environment.
The bivalve fauna of the mudstone can be classified into two ecological groups, viz. infaunal - Nuculids, Edmondia spp, Cypricardella spp, Sanguinolites sp - and epifaunal - pectenids and P. corrugata.

By analogy with modern relatives the nuculids were probably infaunal deposit feeding bivalves (Stanley 1970). The ovate shelled species, N. brevirostris and N. gibbosa, may like modern Nucula proxima (say) (Stanley 1970) have been relatively shallow burrowers while P. laevirostrum and P. attenuata may like modern elongate Yoldia spp (Stanley 1970) have been deeper and more active burrowers. The occurrence of P. attenuata in life position may support this hypothesis though it must be noted that P. laevirostrum is always found as disarticulated valves. Nuculids often show a strong preference for quiet muddy environments (Yonge 1939, Stanley 1970) but the more active and deeper burrowing of P. attenuata may have enabled it to inhabit less stable environments and its occurrence at Catcraig may indicate that this was a rather less stable environment. The remaining infaunal species were probably filter feeders. The swimming abilities of P. fragilis, E. neilsoni and P. corrugata have been discussed by Wilson (1966) and it would seem likely that they and the other pectenid species, with the possible exception of the heavy shelled L. dissimilis were benthonic animals with a swimming ability. E. neilsoni (Wilson 1966) and perhaps some of the other pectenids may have had byssally attached stages like those of modern pectenids (Stanley 1970).
IVL) Phylum Echinodermata - Echinoidea

IVL1 Archaeocidaris urei

Spine and interambulacral plate fragments of Archaeocidaris urei (Fleming) have been found at two levels near the top of the Dunbar Works column. The species is not known from Catcraig or Skateraw though it occurs at these localities in the uppermost bed of the Skateraw Middle Limestone. Fragments of large spines and large interambulacral plates have been found occasionally in the Skateraw Upper Limestone at Dunbar Works.

IVL2 Lepidesthes caledonica

Plates and teeth of Lepidesthes caledonica Jackson have been found in the upper half of the Dunbar Works column and towards the top of the Catcraig column. A doubtful record at Skateraw also occurs towards the top of the column. Numerous plates and other elements have been found in the Skateraw Upper Limestone at Dunbar Works.

In hand specimens from Dunbar Works plates of L. caledonica have been found crowded together on bedding planes and associated with elements of the Aristotle's Lantern. Specimens which were completely disaggregated revealed new information on the characters of the species which has been redescribed (see Appendix). These associations appear to represent the disintegrated remains of a single animal.

IVL3 Lepidesthes cloughi

Plates of Lepidesthes cloughi sp. nov. have been found at several
levels in the upper half of the Dunbar Works column. The species has not been recorded from Catcraig or Skateraw though it occurs at these localities in the uppermost bed of the Skateraw Middle Limestone. Plates and other elements are common in the Skateraw Upper Limestone.

Associations of plates and Lantern elements are found at Dunbar Works and like those of *L. caledonica* probably represent the remains of a single animal. This new species is described in the Appendix and shows several unusual features. Of particular interest are the serrated teeth. These may represent an adaption to rasping at algae (see IVL4) but their growth and structure must be different from the cone-in-cone structure of normal echinoid teeth.

**IVL4 Echinoid Ecology**

Modern echinoids are typically marine animals, though they may occur in waters of lower salinity, and inhabit a wide variety of depths (Durham 1966). The greatest abundance of species is found in shallow waters of less than 100 m (Durham 1966). Regular echinoids are benthonic and, with the exception of the nestling and boring species of rocky substrates, live free upon the sea floor (Durham 1966). Most species are omnivorous but some show predatory or herbivorous tendencies (Durham 1966). Deposit feeding or herbivorous types tend to be gregarious and multi-species herds of echinoids may have devastating effect on the flora of areas of the sea floor (Reese 1966). It is possible that *L. caledonica* and *L. cloughi* formed such groups roaming across areas of the Carboniferous sea floor and feeding on algae and detrital organic matter.
Phylum Echinodermata - Crinoidea

Introduction

Crinoid remains are abundant at all localities and are especially common in the mudstone and Skateraw Upper Limestone at Dunbar Works. However because skeletons are always at least partially broken up into their component ossicles specific identification is usually impossible. Six species of crinoid appear to be most abundant and have easily recognised cup plates and their occurrence in the mudstone has been documented on this basis. Cup plates of other rarer species have also been found in the Dunbar Works column but are not always identifiable and have been included within a generalised group. The species list for the mudstone and Skateraw Upper Limestone is given in table 3 and further comment is restricted to the six dominant species and a small number of the rarer species for which some new information is available.

Crinoid columnals which are only very rarely specifically identifiable have also been recorded as a generalised group and their azimuthal orientation distributions are discussed below. Other specifically unidentifiable features of the crinoid fauna are discussed in the section in crinoid ecology (IVM2).
Though only three cups were found in the Dunbar Works column a large number were collected from the mudstone and Skateraw Upper Limestone. Because of their robust nature the dorsal cups are usually well preserved and thus the species is particularly amenable for biometric analysis. For convenience in data manipulation the specimens have been pooled to form a single sample population but the two subsamples do not differ significantly in either size distribution (Mann-Whitney U test, \( P > 0.39 \)) or anal type ratios (Exact Multinomial Distribution, \( P > 0.664 \)), which are critical factors in the following discussion.

Each of the 76 cups in the population was classified as the type of plate arrangement in the C-D (or anal) interradius according to the scheme devised by Wright (1926, 27) (see explanatory diagram fig 20). This anal variation is apparently a more or less continuous plexus of plate relationships and Wright's classes are obviously to some extent arbitrary artifacts. The system has been used successfully by Wright on a number of inadunate species (Wright 1926, 1927, 1934, 1939, 1951-54) and forms the basis of more expanded classifications erected by Strimple (1948, 1952, 1960). Despite the highly prejudicial class names it has been retained here because of its simplicity and to allow comparison with Wright's (1926) data on *Eocentricus konincki*. The distribution of cup types in the Dunbar population is given in figure 21. One cup in the series has been excluded since its anal structure is distinctly anomalous (fig 22). In this specimen the radianal though obscure lies on the wrong side of the CD basal and the cup appears to be an exact mirror image of the Primitive condition. This is interpreted as an example
of situs inversus which though not known in modern crinoids has been recorded in echinoids (Swan 1966). 'Mirror image' cups are also known in Phanocrinus calyx (Wright 1926) and Phanocrinus arnavossensis (Wright 1951).

Where possible the following variates were also measured - cup width, cup height and width of a radial facet (fig 23). The width of the radial facet was measured on the A-radial wherever possible but to ensure as complete a set of measurements as possible other radials (usually B - or E - radials were also used. Mann-Whitney U tests based on five randomly selected cups in which all five radial facets can be measured show no systematic difference in the facet width of any particular radial. Similarly cup width normally measured across the line of the D-ray and the AB interradius was in some instances measured across the C-ray and the AE-interradius.

The variate frequency distributions (fig 24) all show a marked bimodality with an intermodal minimum at approximately half the maximum size of the variate. Plots on probability paper (Harding 1949) show that the distributions can be regarded as compounded from two normal distributions. There appears to be a tendency for the smaller mode (in terms of frequency and size) to be composed of Primitive type cups, while the other cup types tend to dominate in the larger mode. This impression of a size difference between cup types is supported by the Mann-Whitney U test in which the Primitive group of cups is significantly smaller in each variate (1 tailed tests, P<.01) than either the Advanced or Advanced A group of cups. These latter two groups do not differ significantly in size distribution of any variate either from each other.
or from the Primitive-A group (2 tailed tests, \( P > .50 \)). Because of the small numbers involved it is not possible to test for a difference between the Primitive and Primitive-A groups.

The scatter diagram of cup height against cup width (text fig 25) shows what appears to be a strikingly linear trend and the bimodality and generally smaller size of the Primitive cups can again be seen. Analysis of covariance using the different cup types to define data groups indicates that we are justified in thinking that there is a single over all best fit straight line. The fit of the points is high as indicated by the correlation coefficient of 0.94 (Student's t Test, \( P < .001 \)). The Y-axis intercept of the line is not significantly different from zero. These results are obtained whichever of the variates is specified as the independent variate and similar results are obtained in the analysis of the other two possible variate pairs (text fig 25).

The best fit lines are believed to represent relative growth curves and it is clear that growth must have been a highly coordinated process. Similar high coordination has been recorded in other crinoids and in blastoids (Macurda 1965, 1966).

The lack of cups less than 5 mm in cup width indicates that some modification of the dead population size distribution has occurred. In crinoids the larval and early pentacrinoid phases are not calcified and even where the cup plates have started to develop it may be some time before the plates are well enough sutured for the cups to remain intact.
on the death of the animal. Hence the smallest growth stages will not, except under truly exceptional circumstances, be preserved and it is possible, especially if the juvenile growth rate is high, that in Z. kahincki, whose zygostyngostosial sutures are poorly calcified, the cups of less than 5 mm width would not have survived. The types of post-mortem factors which might affect the preservable growth stages - sorting by currents, solution of shells, and selective crushing and fracture of certain size grades (Hallam in Craig and Oertel 1966) - will probably act selectively against smaller cups. The bimodality of the sample distribution is thus believed to be the abbreviated representation of a bimodal dead population whose absolute mode lay in or close to the smallest size grouping (text fig 26).

Dead population curves of this type can be produced by U-shaped mortality patterns in which the death rate is initially high and then decreases to a minimum before increasing again. Kurten (1964) has suggested that this sort of mortality may be common in the animal kingdom and an obvious example is Homo sapiens (Aksadi and Nemeskeri 1971). Palaeontological examples have been discussed by Olson (1957), Rigby (1958) and Scott (1961). This was not one of the mortality types considered by Craig and Oertel (1966) but numerical curves have been compiled (fig 27) and used with their program and data to generate model populations (figs 27 - 31).

It can be seen that shape of the dead population curves is dominantly controlled by the death rate which gives rise to the pronounced bimodality.
The death rate in modern crinoids is not known but there are several indications that a high juvenile death rate may occur. Most extant crinoid species have free pelagic larvae and in common with other groups with pelagic larvae (Thorson 1950) the mortality is probably high. Observations by Dan and Dan (1961 p 571) suggest that there may be a critical period within which the larvae must settle and the mortality in this phase will probably also be high. The substrates on which the larvae settle may not be suitable for further growth and thus the mortality rate in the post-settlement period will also be high. The high mortality in gerontic stages may represent the cumulative effects of injury, disease and possibly aging.

The type of reproduction in the models is completely masked by the effects of the death rate though it can have a strong effect on the size of the live populations (fig 28). In modern crinoids reproduction appears to be of 'single burst' type (Boolootian in Boolootian 1966) and the outstanding example of this is Comanthus japonicus which spawns regularly at 3 o'clock on the afternoon of a day in early October which can be predicted by consideration of the phase and declination of the moon (Dan and Kuboto 1960).

In the model populations generated using a 'linear' growth rate the intermodal minimum lies at a size which is only about a quarter of the maximum size. A better approximation to the condition in Z. konincki, where the minimum lies at approximately half the maximum size, can be obtained using a 'high-to-low' growth rate (fig 30). The possibility of high
juvenile growth rates has already been suggested. This feature will however also be influenced by the age at which the death rate reaches its minimum value.

The size of the sample is too small to distinguish seasonal effects (Burnaby in Craig and Oertel 1966) though sections cut in detached radial plates show annual bands and it is possible that such variation has occurred. Dan and Dan (1941) indicate that Comanthus japonicus becomes more sensitive to environmental pressures while spawning. In the model populations seasonality effects do not seriously distort the death curves and are in fact most marked in the smaller size groups (figs 29 - 31).

All the model populations have been generated using a coefficient of variation of 2. In the sample population the coefficient of variation of cup width is 32% but when the effects of growth are removed (using the linear regression of cup width on facet width) the coefficient of residual variation is 4.5. Since, as Craig and Oertel (1966) note, the variation of the product is greater than the underlying mechanism, it is clear that variation in Z. konincki must be small.

On the basis of the preceding interpretation of the features of the frequency distributions the smaller size of the Primitive cups must also be interpreted as a growth feature. It is suggested that the immature individuals tend to have a Primitive anal structure and that as they grew the differential growth of the anal plates caused an apparent
rearrangement and modification of the anal structure of the cups.
The plate pattern on the internal face of a cup is often markedly
different from that on the outside and where possible the internal anal
structure was noted and classified according to a slightly modified
version of Wright's scheme. This modification was required since in
some cups the radials penetrate through the basal circlet and make contact
with the infrabasal circlet. In such circumstances the terms Primitive
or Advanced were still applied if the radianal also made contact with
the infrabasal circlet. The results (fig 32) show that there is a
distinct tendency for the internal pattern to be of Primitive type and that
in no case does a Primitive cup show a more 'mature' structure internally.
The sections cut in disarticulated radial plates show that plate growth
took place by accretion on all faces and thus the internal arrangement
of the anal plates cannot be regarded as a frozen neanic structure.
Nevertheless, since accretion on internal faces is less than on external
faces, the amount of structural modification by differential growth
is probably less and thus the internal structure will have a closer
resemblance to the neanic structure. Thus the tendency to Primitiveness
in the internal patterns is believed to support the hypothesis of change
of structure by differential growth. In 3 cups in the sample the anal
X is seen to have been occluded during growth and it no longer appears
on the external surface. The hypothesis of change of anal type with
growth cannot however account for all the variation seen in the Dunbar
population since the larger mode of mature individuals is composed of
almost equal numbers of Advanced and Advanced A cups, accompanied by a
few Primitive and Primitive A cups.
The frequencies of the different anal types in the Dunbar population can be compared with frequencies recorded by Wright (1926 p 158) for populations from three localities in West Fife - Invertiel (No 1 bed), Roscobie and Seafield (fig 21) - and the distributions are significantly different (Chi Square Tests and Exact Multinomial Distribution, $P < .01$). Consideration of the deviations on which the test is based (fig 21) show that the contribution of the Primitive and Primitive A classes is small and that the bulk of the deviations is supplied in almost equal proportions by the Advanced and Advanced A classes. If these two classes are pooled then the Dunbar and Fife populations do not differ significantly (Chi Square Test and Exact Multinomial Distribution, $P > .05$). No other combination of two classes reduces the deviations to an insignificant level. The Roscobie and Seafield populations do not differ significantly from each other ($P > .05$) nor do they differ significantly from the Invertiel population ($P > .05$) though once again the bulk of the deviations lies in the Advanced and Advanced A groups.

The differing numbers of Advanced and Advanced A cups might be due to a difference in interpretation of class boundaries. Since the discriminating factor (relationship between the radianal and BC-basel) also between Primitive and Primitive A cups a consistent bias in application of class boundaries should also affect their frequencies which does not seem to have occurred. Unfortunately Wright's original collection has become dispersed but some of his figured specimens (Wright 1926, 1932, 1951 - 4) can be identified in the collections of the Royal Scottish Museum and have allowed a visual comparison with cups whose anal pattern
has also been classified by Wright. No systematic difference in classification was found.

2114 cups or crowns of Zeacrinites konincki in the Royal Scottish Museum collections were measured for the three variates. This collection which also includes cups from several localities other than those mentioned above is obviously biased towards the larger sizes but the variate frequency distributions show a similar size range (e.g. cup width 5.0 - 21.4 mm), bimodality and intermodal minimum to those of the Dunbar population and there is again a tendency for the Primitive cups to be smaller. Analysis of covariance of the variate pairs shows that the Dunbar and Royal Scottish Museum material can be represented by single best-fit straight lines whose Y-axis intercept is not significantly different from zero.

The similarity in growth lines and in features of the frequency distributions suggests that the different populations have been governed by the same life and mortality patterns. Thus the similarity of proportions of Primitive (i.e. smaller, immature) cups in the Dunbar and Fife populations is interpreted as indicating that these collections are equally biased in terms of size. The differing relative proportions of Advanced and Advanced A (i.e. larger mature) cups is interpreted as a real biological feature of the adult populations of these localities.

These adult variations which exist both within and between populations may be due to ecological or genetic factors or to a combination of both.
The ecological hypothesis was clearly favoured by Wright (1926, 1952) and by Kirk (1937) but it cannot fully explain the variation within a population and there is moreover the fact that at Dunbar the cup type frequencies do not alter with the change from mudstone to limestone. Available data (based on the Royal Scottish Museum collection) suggests that the ratio of Advanced to Advanced A cups at Invertiel is also stable over the environmental changes between the deposition of beds 1 and 3 (for local succession see Wright 1912).

Genetic variation may be either sex-linked or autosomal. The relative proportions of Advanced and Advanced A cups at Dunbar are suggestive of a sex ratio but the numbers at the Fife localities are less so. The sexual dimorphism hypothesis however suggests a meristic variation whereas the classes are convenient subdivisions of a continuous variation and it is therefore suggested that the dominant source of variation is differences in the autosomal gene pools. The localities all lie in mudstone-limestone sequences overlying thick limestones and are all believed to represent the local development of the early regressive phases of the same cyclothem. It is thus impossible to distinguish between the localities chronologically and to estimate the relative importance of temporal or spatial variation. The proximity (c 1 mi.) of seafield and Invertiel does however suggest that between these two localities at least the variation is dominantly geographical in nature.

The present study has confirmed and extended Wright's (1926) account of variation within Z. konincki and it is clear that it also endorses the
statement that 'the size and disposition of anal plates alone is not always a sure guide in the discrimination of species' (Wright 1939). Grave doubt must be cast on those species which have been discriminated solely on the basis of their anal structure. For example Sutton and Hagen (1939) who did not recognise intraspecific anal variation described several new species of Zeacrinites which were often distinguished from other species of Zeacrinites on the basis of the nature of the CD interradius and this discrimination was often carried out at a much more refined level than that used in Wright's classification. The problem of intraspecific variation is particularly serious in crinoids since species descriptions often have to be based on very limited numbers of specimens. In the British Carboniferous (table 11) more than 80% of all cladoid inadunate crinoid species have been described on fewer than 10 specimens and only 2.4% have been described on more than 100 specimens. Though it is not suggested that variation of the CD interradius occurs in every species it is clear that species in which anal variation has been recognised tend to be among the better known species (table 11). The problem is compounded in those species where variation of the CD-interradius is associated with other intraspecific variations. For instance in Ureocrinus bockschii it is associated with a wide variation in cup shape (Wright 1927). In addition to its taxonomic importance the structure of the CD-interradius of Late Palaeozoic inadunate crinoids is important in evolutionary considerations. It is generally agreed (e.g. Moore and Laudon 1943, Moore, 1952, Strimple 1960) that in the course of evolution the CD-interradius becomes modified by the gradual elimination of all anal plates from the cup
and this modification is said to take place by two processes - resorption or expulsion upwards (Moore and Laudon 1943). The ontogenetic development of the anal series in *Z. konincki* follows a pattern in which an apparent upward migration of plates occurs and it is possible that the various populations of *Z. konincki* represent different stages of a species in the process of evolution. Evolutionary modifications have appeared in the adult growth stages and further evolution may follow two paths. Firstly the advanced structures may develop progressively earlier during an animal's life history causing diminution, occlusion and perhaps even elimination (resorption) of plates. Secondly the variability may become focused round one or more lines of modification. The similar proportion of Primitive cups in the various populations suggests that they have not been affected by heterochronous processes of the first type but in fact the evidence is probably lost due to the low death rates prevalent during the critical growth stages. A polarisation towards one particular variant is evident in the Fife populations and it is interesting to note that these populations also produced more highly modified plate patterns (e.g. Wright 1926 fig 37, 38) than have been found at Dunbar. *Z. konincki* thus may be evolving by reduction of firstly the anal X and secondly the radianal and the differences between the Dunbar and the Fife populations may reflect temporal and spatial variations in the gene frequencies.

The concept of evolutionary modification of the CD-interray is implicit in the highly prejudicial nomenclature used by Wright (1926) and is also evident in an extended classification developed by Strimple (1960) which is built round three developmental trends which he believes to
characterise the evolution of the anal series. The sequence suggested for *Z. konincki* does not follow any of these trends and since some of the Dunbar cups fall outside this classification scheme a more detailed treatment has not been attempted.

Though it is unlikely that other examples of intraspecific variation in the CD-interradius follow the same pattern as the variation in *Z. konincki* a closer study of such variations may well reveal more detail of evolutionary processes in this interradius. In *Z. konincki* the recognition of differential growth of anal plates is facilitated by the form of the cup which necessitates that accretion should take place on all faces of cup plates. It is interesting to note that similar occluded and wedge shaped anal plates occur in other bowl-shaped crinoid species e.g. *Stuartwellercrinus symmetricus* (Moore and Laudon 1943 plate 6, fig 6c), *Paradelocrinus decoratus* (Burke 1970, p. 10), *Atokacrinus obscurus* (Koepf 1969, plate 61, fig 3).

**IVM3 Phanocrinus gordonii**

The small phanocrinoid species *Phanocrinus gordonii* Wright is one of the dominant crinoids in the upper parts of the Dunbar Works column and though rather less common than *Zeacrinites konincki* is found at lower levels than that species. Detached radial plates of *P. gordonii* have been found in the Catcraig and Skateraw columns. Cups and cup fragments of *P. gordonii* are common in the Skateraw Upper Limestone at Dunbar Works.
This species like *Z. konincki* (section IVM2) shows variation of the CD-interray but due to the depressions which occur at the angles between plates it is not always possible to determine the anal type. The distribution recorded is - Primitive 6, Primitive A 17, Advanced A 5, ? 11. Comparative quantitative data from elsewhere is not available (Wright 1951). The size frequency distribution for variates measured in the same manner as those of *Z. konincki* (IVM2) is given in table 15. Some indication of a bimodal distribution can be seen in the measurements of cup width but it appears that the juvenile mode has lain entirely with the zone of non or poor preservation.

IVM1: *Urecrinus bockshii*

*Urecrinus bockshii* (Geinitz) is the only inadunate crinoid to have been recorded from Catcraig or Skateraw. The species occurs throughout the Catcraig column and at the top and base of the Skateraw column. Only a single cup plate was recorded in the Dunbar Works column though cups of this species have been found at this locality (supplementary collection). Cups and cup plates of *U. bockshii* also occur in the Skateraw Upper Limestone.

*U. bockshii* is unique among Scottish Carboniferous Crinoids in having a wide stratigraphic range (Calciferous Sandstone Measures to Upper Limestone Group) and occurs at a large number of horizons within this range (e.g. in the Dunbar area where only part of its range is exposed cups have been found at five other horizons. In these occurrences *U. bockshii* is often the only crinoid which is found and this suggests
that it could not only withstand a wide variety of environments but was also a solitary crinoid rather than one which flourished in large gardens. The distribution of *U. bockschii* in the mudstone supports this idea as it is most common away from Dunbar Works which appears to have formed the main locus for crinoid development.

Like that of *Z. konincki* (section IVM2) the C-D interradius of *U. bockschii* shows considerable variation (Wright 1927). The variation at Dunbar (Advanced cups - 19, Advanced A cups - 2) is significantly less marked than that found in approximately contemporaneous faunas in Fife (Wright 1927) but due to the small sample and known variation in cup shape no further study has been attempted. The wide stratigraphic range would however make this an extremely interesting species to study.

**IVM5 Fifeocrinus tielensis**

In addition to plates of the normal form of *Fifeocrinus tielensis* (Wright) an ornamented variety has been recorded from the mudstone and Skateraw Upper Limestone at Dunbar Works. The ornament consists of coarse pustules which often have a central crater and which are irregularly distributed over the surface of the cup (? and arms). The distribution and cratering suggest a parasitic infestation but in the circumstance the parasite would have to have been highly specific as to its host and would also have had to attain a high level of infestation in every instance.
Records of *Talenterocrinus redesdalensis* Wright in the mudstone and Skateraw Upper Limestone at Dunbar Works are based on a cup and a number of cup fragments. The cup is identical to those figured by Wright (1953). This is the first record of *T. redesdalensis* from such a high stratigraphic level. Previously recorded specimens have come from the Cove Marine Band of the B2 age (Wright 1953, Wilson 1952). At Invertiel this species appears to be replaced by *T. strimplei* (Wright 1953).

Columnals and disarticulated cup plates of *Camptocrinus compressus* Wright have been found in the mudstone and Skateraw Upper Limestone at Dunbar Works. The association between the compressed columnals and cups postulated by Wright (1958) is borne out by the fact that the column facet on basel circlets is elongate and has its long axis at right angles to the antero-posterior axis of the cup.

A long spiniferous primibrach similar to those of the D-ray of *Idosocrinus bispinosus* or *I. tumidus* has been found in the Skateraw Upper Limestone. The specimen is worn but appears to have lacked ornament. No other unornamented phanocrinoid remains have been recognised from the Skateraw Upper Limestone at Dunbar Works. This is the first record of *Idosocrinus* from the Lower Limestone Group. The other Scottish species are found in the Cove Marine Band at a stratigraphically much lower position (Wright 1958).
IVM9 Phanocrinus calyx

Only three cups of Phanocrinus calyx (McCoy) have been found in the mudstone at Dunbar Works. The species has not been recorded at either of the other localities or from the Skateraw Upper Limestone.

The scarcity of P. calyx in the Dunbar crinoid fauna is one of the major differences between this fauna and the approximately contemporaneous Invertiel fauna (Wright 1912, 1951 - 1), The reasons for this are not clear. All three cups are of Primitive anal type which is the dominant type in the Invertiel Nol Bed population (Wright 1926).

IVM10 Phanocrinus' stellaris

A single cup of Phanocrinus stellaris (Wright) has been found in the mudstone at Dunbar Works. In the hand specimen a large number of brachials were associated with this cup and, as they resemble it in ornament, are believed to have been derived from the same individual. Among these brachials at least two types of axil can be recognised and this indicates as suspected by Wright (1951 - 1) that the species cannot strictly be assigned to the ten armed genus Phanocrinus. The correct re-assignment cannot however be made since the exact number of arms is unknown.

IVM11 Dichocrinus spp.

Two species of Dichocrinus appear to occur in the mudstone at Dunbar Works. The material of the first consists of a small cup with a fine granular ornament similar to Dichocrinus fusiformis (Wright 1958) though apparently slightly taller than that species. Similar radials have been found in washed residues. The second species has only been recognised
in material from washed residues but both radials and half basal circlets have been found. This species is unornamented. These are the first records of *Dichocrinus* in Scotland.

**IVM12 Platycrinites conglobatus**

*Platycrinites conglobatus* (Wright) is the dominant crinoid of the fauna and is found at nearly every level in the Dunbar Works column. Occasional cup plates of *P. conglobatus* are also found at Catcraig and Skateraw and the species is extremely common in the Skateraw Upper Limestone at Dunbar Works.

Most records are of detached basal or radial plates but squashed cups and calices are not uncommon in the mudstone and Skateraw Upper Limestone at Dunbar Works. At several levels in the Dunbar Works column groups of 5 radials, 1 basal and numerous tegmenals were found associated together in a manner suggesting that they were derived from the disintegration of a single calyx. This sort of phenomenon has been noted in other crinoid species in the mudstone e.g. *Phanocrinus stellarius* (IVM10) and also *Fifeocrinus tielensis*. The way up distribution of radial plates and basals is given in table 16. In both radials and basals there is a tendency for the concave-up position to predominate though this is most marked in the basals. Though the curvature of radials and basals is not great the convex-up position might be expected to be more stable and the present distribution may thus indicate a fairly low energy environment. The ratio of concave up to convex up fluctuates in the column but there is no evidence of a trend in either radials or basals nor indeed are the
fluctuations always synchronous. The overall ratio of radials to basals is 0.489 which is extremely close to the expected value of 5 and again indicates a lack of sorting.

Size frequency data for basals collected from the mudstone and limestone at Dunbar Works is given in table 17. The distribution is unimodal and a juvenile mode, if it existed, must have lain in the field of microscopic size.

Included with P. conglobatus as here used have been a number of radials and basals of P. conglobatus type but carrying an ornament. This ornament is very variable but at times approaches that of Platycrinites? invertielensis (Wright) (Wright 1956), A complete passage appears to exist between ornamented and unornamented plates and it has proved impossible to subdivide the group clearly.

IVM13 Other platycrinoids

Two other species of Platycrinoid - Platycrinites crassiconicus (Wright) and Platycrinites? spiniger (Wright) are known from the mudstone and Skateraw Upper Limestone at Dunbar Works. P? spiniger is found at a variety of levels throughout the Dunbar Works column but P. crassiconicus which is very frequent towards the top is not found at the base of the column. Both species are recorded entirely as disarticulated cup plates and rare fragments especially of P? spiniger have been found at Catcraig and Skateraw.

IVM14 Crinoid columnals

Crinoid columnals are common in the mudstone and Skateraw Upper
Limestone at all localities but with the exception of those of *Camptocrinus compressus*, *Mesoplotoctinus pringlei* and *Platycrinites* spp cannot be identified.

The nature of columnals of *C. compressus* and *M. pringlei* suggests that the crowns were pendant from a curved stem but the adaptive significance of this is not clear. The ellipsoidal columnals of *Platycrinites* spp have elongate articular facets, the orientation of which changes along the stem. The stems of these species must therefore have had considerable flexibility in all directions - a feature which would have been of considerable assistance in regimes where currents varied in direction and strength.

The orientation of columnals has been measured at all levels in the mudstone of each locality and selected distributions are illustrated in figures 33 - 5. These distributions are very variable but generally have wide often double maxima in a ESE - WNW or SE - NW lineation and a narrower maxima in N - S or NNE - SSW lineation. Schwarzacher (1963) has demonstrated with flume studies how such orientation distribution can arise but it is far from clear as to how the prominence of the various modes will vary with differences in current strength and substrate character. The wider mode probably represents columnals which have been aligned across the direction of flow and thus suggest that the current lineation has been approximately north south. 'T' and 'V' shaped columnal alignaments are totally ambiguous as to the possible direction of flow and though many suggest currents with a N - S lineation others...
indicate an approximately SE - NW lineation. It is thus possible that
the distributions have resulted from the interaction of two current systems.

IVM15  Crinoid Ecology

The ecology of modern crinoids has been reviewed by Fell (1966) and Cain
(1968). They are exclusively marine animals as probably were their Palaeozoic
ancestors and are most abundant in relatively shallow (shelf) waters.

As a group crinoids are probably moderately rheophile and avoid stagnant
areas but excessive water motion cannot usually be tolerated due to the
delicacy of the skeleton.

Stalked crinoids such as the Palaeozoic forms must have had an intimate
dependence on their substrate and in both the mudstone and Skateraw Upper
Limestone large sections of root have been found though none was in a life
position. In washed residues from the mudstone at Dunbar Works crinoid
columnals and cirrals have been found whose growth has interfered with, and
been modified by, the growth of bryozoa and other crinoids. Some of such
phenomena are probably accidental but others may have helped the crinoid to
support itself. In the Skateraw Upper Limestone a few basal discs have been
found cemented on corals and on detached cup plates.

The presence of quantities of suspended sediment is inimical to
crinoids and the great increase in abundance of crinoids at the top of the
mudstone and in the Skateraw Upper Limestone at Dunbar Works may indicate a
reduction in the turbidity of the environment.
Modern crinoids due to their generally sessile nature are commonly involved in parasitic and commensal relationships with other organisms (Clark 1921) and there is evidence that this occurred in the present fossil example e.g. *Myzostomites*, *Platyceiras*, *Onychaster*.

IVN) Phylum Echinodermata - other echinoderms

IVN1 Astrocrinus bennisi

Fragments of this small blastoid have been found in washed residues from the mudstone at Dunbar Works. The species has not been found in the Skateraw Upper Limestone or at Catcraig or Skateraw. *A. bennisi* (Etheridge) has been recorded from Skateraw and East Barns (Etheridge 1876, Clough et al 1910).

The adaptive features which enabled this stemless blastoid to survive in a muddy environment are not clear.

IVN2 Onychaster flexilis

Vertebrae and parts of the mouth frame of *Onychaster flexilis* Meek and Worthen have been found in washed residues of the mudstone at Dunbar Works and a single vertebra was recognised during the extraction. Vertebrae have also been found in the Skateraw Upper Limestone at Dunbar Works and in the mudstone at Skateraw.

Spencer (1914) has compared *Onychaster flexilis* with modern *Astrophyton* - like forms which at the present day live epifaunally on zoophytes. He believes that *Onychaster* had a similar mode of life on
crinoids using them as a support from which to gather food.

IVO) Phylum Hemichordata - Graptolithina

IVO1 Dendroid Graptolites

Two species of dendroid grapholite are found in the mudstone at Dunbar Works but apart from very dubious records in the Skateraw Upper Limestone at Dunbar Works are not found elsewhere. Both species are described in the appendix and further discussion of their distribution is given there.

Dendroid graptolites with the exception of Dictyonema flabelliforme are generally agreed to have been attached to the sea floor (Bulman 1970) but more detailed accounts of their ecology are lacking. One of the most interesting occurrences is the Gasport lens (Ruedemann 1925) where they occur in what appears to have been a channel running through a crinoidal coralline limestone. This suggests that some dendroid graptolites at least were adapted to environments of moderate energy though excessive motion would probably have damaged them.

IVP) Trace fossils

IVP1 Introduction

The mudstone at all three localities contains pyritic or sideritic trace fossils. The diagenetic origin of the mineralisations has already been discussed (Section III) and a stratified burrowing system recognised - shallow burrowers are pyritised and deeper burrowers sideritised. The purpose of this section is to give further details on the nature of the
different burrow types. Due to the fact that pyrite decomposes rapidly in the extraction process it has not been possible to gain information on the distribution of pyritised trace-fossils within the columns. In the field pyritised burrows have been recognised throughout the mudstone at each locality.

**IVP2 Pyritised trace fossils**

The dominant type of pyritised trace fossil is a linear burrow. Normally these burrows have collapsed and are represented as streaks on bedding surfaces but occasionally solid cylindrical tubes of pyrite may be found representing infill of an open burrow. Transitions from open to collapsed types have been found. The size of these burrows varies considerably but two widths (about 1 mm and 3 mm) appear to be common. In one case a scolecodont assemblage has been found lying in a pyritised streak and may represent the remains of the burrowing animal. The burrows thus seem to be the shallow Domichnia or Fodinichnia of a worm.

At Dunbar Works a number of other pyritised trace fossil types have been recognised. The most common of these are sheetlike or three-dimensional networks of thin (less than 1 mm) flattened pyrite tubes. The sheetlike networks bear a strong resemblance to *Palaeodictyon* and these burrows probably represent shallow Pascichnia. The remaining trace fossil types are rather doubtful and consist of irregular films of pyrite covering areas of bedding surfaces or of petaloid arrangements of pyritic films. It is possible that these might be of algal or other origin.
The linear trace fossils may occasionally be found sideritised and the 'chondritid' siderite burrow may occasionally be found to have been pyritised.

IVP3 Sideritised trace fossils

The dominant type of sideritised trace fossils are the 'halo' burrows which have been recorded in all three columns. 'Halo' burrows when maximally developed consist of sideritised tubes with a mudstone infill. Normally however the tubes are incomplete and gutter like modules are found. The concavity of the gutter may face in any direction but it is usually concave up. The sideritisation is believed to have been controlled by mucous burrow linings and in some cases squashed tubes are found indicating the sideritisation of a collapsed burrow. These burrows are similar in character to burrows of unknown composition preserved in recent oceanic sediments in the Pacific (Donahue 1971).

Of secondary importance are the Zoophycos laminae which are common towards the top of the Catcraig and Skateraw columns. They have also been found occasionally at Dunbar Works though not recorded in the column. The sideritised laminae are thick (10 - 15 mm) fairly high angle systems of complex crescentic gutter shaped spreite and are at Catcraig and Skateraw associated with unmineralised flat thin (2 - 3 mm) Zoophycos laminae. Passages between the two have been observed and their differences appear to be related to the effects of compaction. A compaction factor for the mudstone in the order of 5 is therefore indicated.
The third type of sideritized burrow system has not been recorded in the columns though found at Skateraw and Dunbaw Works. These burrow systems have an outwardly similar appearance to Chondrites and closely resemble ironstone burrows recorded from this, the Neilson Sheál Bed, horizon in West Fife (Chisholm 1970). They differ from Chondrites in their spiral like bushy branching and in the fact that burrows may remain open and become mineralised. Occasional specimens of this species may be pyritised.

A few sideritized tubes equivalent to the linear pyritised burrows have been recorded.

IVPh Trace fossil ecology

Much has been written on trace fossil bathymetry since the pioneering work of Seilacher (1964, 1967) but it is here felt that less emphasis should be placed on bathymetry and more consideration given to interpreting burrows as a response to environmental stability and to the availability and supply of nutrients.

The absence of complex domicnian burrows of Cruziana, Glossifungites or Rhizocorallium type probably indicates a stable environment while the absence of highly developed and extensive burrow systems of Nereites type probably indicates that there was not great shortage of food.
IVQ) Phylum Chordata

IVQ1 Fish remains

The fish remains of the mudstone fall into three taxonomic groups—viz. elasmobranchs, crossopterygians, and palaeoniscids. Members of all three groups have been recorded in each column. Only elasmobranch remains here have been recorded from the Skateraw Upper Limestone.

The elasmobranch remains consist of isolated raptorial teeth of cladoselachian sharks and isolated crushing teeth of petalodont and cochliodont sharks (for species names see table 3). Though the shark fauna is diverse species are represented by only a few finds. According to Traquair (1903) these sharks are characteristic marine forms and the teeth are the only parts of the animal which might be expected to survive under conditions of rapid aerobic decay (Zangerl and Richardson 1963, Schäfer 1972). The cladoselachian sharks probably represent active pelagic carnivores or omnivores while the petalodonts and cochliodonts may represent slower moving bottom dwelling forms which preyed on shelled benthos (Romer 1966). Though the provenance of the teeth is doubtful it is possible that both types of shark were attracted to the local area of high biomass in the same way as some modern sharks and rays frequent reefs (Friedrich 1969).

The crossopterygian remains consist mainly of parts of a coelacanth (Rhabdoderma sp) though some rhipidistian scales have also been found. The coelacanth remains show a peculiar bias since with the exception of a single scale only isolated dermal or endocranial bones have been found. The cycloid scales of a coelacanth would be expected to have at least as good a preservation potential as dermal bones. Schäfer (1972)
has shown that during the decay of fish the head and body may become separated and the high cranial kinesis of coelacanths (Thomson 1969) would perhaps promote such a process. Coelacanth heads thus seem to be an exotic element in the fauna but since Carboniferous coelacanths appear to have inhabited both marine and non-marine environments their provenance is unknown.

Rhipidistan and palaeoniscid fish are believed to be fresh water forms (Traquair 1903) and their occurrences in the mudstone are believed to represent the remains of the occasional bloated cadaver which has been washed out to sea.

IVR) Kingdom Plantae
IVR1 Plant Remains

Terrestrial plant remains have been noticed on a few hand specimens of mudstone from Dunbar Works and obscure remains were recorded in the column. The fragments are robust (â. 100 mm long) partially pyritised pieces of straplike leaves (Cordaites sp) and stems. The problems of distinguishing between Cordaites leaves and compacted stems has been discussed by Mensah and Chaloner (1971) but the Dunbar specimens are thin and give no indication of having had axial structures. Terrestrial plant remains have been found in a wide variety of recent marine deposits (Uchupi and Jones 1967) and the absence of small fragments which would waterlog more quickly may indicate that the Dunbar area is at some distance from the source land mass.
VA) **Introduction**

The tabulated results from the columns (enclosure 1) and the faunal list (table 3) form a bewildering array of information. On a subjective basis distinct faunal differences can be seen between localities but there are also strong similarities. Within localities variation appears to be cryptic and no strong pattern of faunal change such as those found in the Second Abden Shale (Ferguson 1960), Top Hosie Shale (Craig 1951) or shales below the Coral Limestone, Corrieburn, (MacDonald 1966) can be recognised. To resolve this problem and to give a more objective assessment the data have been subjected to an association analysis of the type which has become a standard technique among phytosociologists (Ivimey-Cook and Proctor 1966, Williams and Lambert 1959, 1960) and similar to those used on geological data by Johnson (1962) and by MacDonald (1966).

The data have been treated in binary form on a presence - absence basis and doubtful records have been ignored. This may introduce some bias as a fragment may have the same status as a shell but more numerical analyses would entail many subjective value judgements as to the weighting of fragments and valves. Such weighting would have to vary from species to species. In addition the fossil abundance of a species is not a simple expression of its former abundance as an animal but is modified by the effects of population structure, mode of growth, longevity, taphonomy and sediment dilution.
The volume of association indices to be computed and compared (the present study comprises 19,306 pairings) places a limit on the computer space available and some reduction of the data has been necessary. Species not represented in more than 5% of the total number of levels have been removed from the analysis. The species used are indicated on enclosure 1.

The association analysis has been performed in the Q-mode in order that levels might be grouped and characterised on the basis of their fossil content. The groups so derived are thus not strictly communities (which would require an R-mode analysis) but are essentially biofacies. Palaeosynecological interpretations can however be made by analysing the species which occur in each biofacies group.

A wide variety of association indices have been applied to presence-absence data (Kershaw 1964, Cheetham and Hazel 1969) and the index chosen for the present study was a chi-square index - $X^2/n$. Some doubts have been expressed as to the suitability of chi-square indices (Kershaw 1964) since their calculation appears to involve the assumption that the probability of occurrence of a species is constant for all samples. This objection undoubtedly pertains where one attempts to use the chi-square in a significance test from which probabilities will be derived but do not seem serious objections to the use of the statistic itself as a measure of association. Groupings obtained using chi-square are frequently similar though clearer than those found using other indices and this may be due to the highly skewed nature of the chi-square distribution.
Biofacies and their interpretation

Biofacies Groups

The results of the association analysis are given in dendrogram form in enclosure 2. At the most refined level a large number of very small groups could be recognised but these cluster in eight larger groupings which have been used to define eight biofacies within the mudstone sequences (see enclosure 2). The variation in biofacies throughout the columns is illustrated graphically in enclosure 1.

The species occurring within each biofacies have been tabulated (tables 18 - 25) and their degree of presence classified according to the following scheme -

<table>
<thead>
<tr>
<th>Degree</th>
<th>Occur in</th>
<th>Biofacies Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant</td>
<td>100 - 80%</td>
<td></td>
</tr>
<tr>
<td>abundant</td>
<td>80 - 60%</td>
<td></td>
</tr>
<tr>
<td>common</td>
<td>60 - 40%</td>
<td></td>
</tr>
<tr>
<td>seldom</td>
<td>40 - 20%</td>
<td></td>
</tr>
<tr>
<td>rare</td>
<td>20 - 0%</td>
<td></td>
</tr>
</tbody>
</table>

Rare species have been omitted from further study, which has taken the form of a trophic analysis of the species within a biofacies, though included within indices based on species numbers.

Biofacies 1

Biofacies 1 is restricted in its occurrence to the Dunbar Works column where it occurs largely in the uppermost 820 mm though it does
develop as low down as 1800 mm below the top (enclosure 1).

The fauna (table 18) is dominated by filter feeders and a stratification into high, medium and low level feeding zones was probably present. The high level filter feeders (crinoids) appear to predominate and the efficiency of these combined with possible baffle effects of the crinoid stems may have reduced the abundance of the low level filter feeding brachiopods though these are well diversified.

The average number of species per level is relatively high and due to the groupings of inadunate species and bryozoan species is probably considerably underestimated.

There is a strong resemblance between this biofacies and biofacies 2 though they may differ slightly in trophic structure (table 19, section VB3). In terms of species the most notable differences are the presence of *Echinoconchus punctatus*, *Zeacrinites konincki*, *Serpulites carbonarius* in biofacies 1 and the absence of *Weberides mucronatus*, *Dielasma aff gillingense*, *Pleuropugnoides pleurodon* and *Phricodothyris lineata* from biofacies 1. The fauna of biofacies 1 also closely resembles the fauna of the Skateraw Upper Limestone at Dunbar Works (table 3). The main difference is the absence of *Claviphyllum eruca* from biofacies 1.

There is some similarity between the fauna of biofacies 1 and the Crawfordsville crinoid fauna of Indiana (Lane 1963) and it is possible that the high level filter feeding crinoids of biofacies 1 were themselves...
stratified into superior and inferior zones. A similar assemblage with crinoids, Echinoconchus, Cleiothyridina, Composita, productoids and bryozoa has been recognised in the Pennsylvanian of Illinois and has been interpreted as an off-shore community of firm calcareous to carbonate muds (Johnson 1962). Johnson's community was included by Bretsky (1969) in his loosely knit Productid-chonetid association and similar though crinoid poor faunas occur in Scotland in the Second Abden Shale (topozone h) (Ferguson 1960, 1962) and in the shales under the Coral Limestone, Corrieburn (MacDonald 1966). The biofacies is not represented in the Neilson Shell Bed localities studied by Wilson (1966) but specimens collected on a brief visit to Invertiel suggest that it is present at this locality.

The highly stratified filter feeding structure of the biofacies suggests that sedimentation was low and the water non-turbid since an abundance of mud would clog up the food grooves and lophophores of the component species. It has previously been suggested that crinoids were moderately rheophile (section 17M15) and a moderate amount of water movement would help to maintain a constant supply of food particles. The transition to the Skateraw Upper Limestone facies probably occurred by increasing energy of the environment and by reduced sedimentation and turbidity.

**Biofacies 2**

Biofacies 2 is almost completely confined to the mudstone at Dunbar Works and the single occurrences of this facies at Skateraw and Catorcaig.
are regarded as spurious (see section VC). At Dunbar Works the facies develops sporadically between 0 and 3050 mm below the top but is largely confined to a zone from 830 to 3050 mm below the top of the mudstone (enclosure 1).

The faunal composition of the biofacies is given in table 19 and the fauna has previously been compared with that of biofacies 1 (see section VB2). A stratified filter feeding system can be recognised as in biofacies 1 but in this facies the lower levels of the system are dominant and there is a diverse brachiopod fauna. The abundance of the probably omnivorous Weberides may also be linked with this.

Like biofacies 1 this biofacies contains elements similar to some of those in Johnson's (1960) Group I assemblage (e.g. Crinoids, bryozoan, small chonetids, spiriferids, productids) and some of these are also evident in the Second Abden Shale (topozone 4) (Ferguson 1960, 1962) and in the shales under the Coral Limestone (MacDonald 1966).

The reduction in the crinoid fauna of this biofacies is interpreted as due to reduced amounts of water movement though the high development of the filter feeding system suggests that the waters were still non-turbid. Like that of biofacies 1 as interpreted by Johnson (1962) the substrate was probably fairly firm.

VB4 Biofacies 3

Biofacies 3 is only developed at Dunbar Works where it occurs
sporadically between 430 mm and 3400 mm below the top of the column (enclosure 1).

The faunal composition is similar to that of biofacies 2 (tables 19, 20) but in this biofacies both high and low levels of the filter feeding stratification are somewhat reduced. The fauna still falls within Johnson's (1962) Group I assemblage.

It is suggested that this is a low energy environment like that of biofacies 2 (section VB3) but that there is a slightly increased turbidity causing a reduction in the efficiency of filter feeding mechanisms. The increased turbidity and probably higher sedimentation rate may also have rendered the bottom slightly softer than in biofacies 1 and 2. The increased abundance of a deposit feeder ('Halo' burrows) may be related to these changes but as burrowing occurs at and is preserved at a lower level than the epifauna with which it is associated no great importance can be attached to it.

**VB5 Biofacies 4**

This Biofacies occurs at both Skateraw and Dunbar Works. In both columns it is most common towards the base (Dunbar Works 330 - 3720 mm, especially 1810 - 3720 mm; Skateraw 380 - 900 mm).

The faunal trends evident in the previous three biofacies are continued in this biofacies (table 21). The abundance of both crinoids and brachiopods is lower and since the abundance of both byrozoa and crinoids is probably seriously overestimated due to fragmentation and disarticulation the stratified feeding system appears to have broken down. There is no obvious noncomittant increase in other trophic levels but this may be concealed due to the inability to sample the pyritised trace fossils.

This facies is interpreted as a more turbid equivalent of biofacies 3.
Biofacies 5

Biofacies 5 is not well represented in the columns though it is developed at both Skateraw and Dunbar Works. At Dunbar Works it is found as high up as 1610 mm below the top but is largely confined to a zone between 3100 mm and 3630 mm below the top of the column. At Skateraw there is only a minor development between 290 mm and 360 mm below the top of the succession.

This biofacies is apparently the most diverse of the eight biofacies (average number of species per level = 18.7, table 22) but at the levels at which it occurs the abundance of crinoids and bryozoa is probably overestimated since there are few records of these in each level. The dominant trophic group is the low level epifaunal filter feeders in which both brachiopods and the vagile pectinid bivalves are well represented. The probably herbivorous or omnivorous gastropods are also well represented in this facies.

The abundance of *Crurithyris urei* in association with *Eomarginifera longispina* is reminiscent of topozone 3 of the second Abden Shale (Ferguson 1960, 1962) which also contains bellerophontid gastropods. There are however many differences notably the abundance of *Torniquistia polita* and *Pleuropugnoides pleurodon* and the absence of *Schizophoria resupinata* at Dunbar. The Biofacies 5 fauna also approaches that of the Central Facies of the Neilson Shell Bed though nuculid bivalves are absent. Of the Pennsylvanian assemblages (Johnson 1962) the closest appears to be the Group II assemblage containing *Crurithyris planoconvex*.
and bellerophotid and other gastropods though once again nuculid bivalves are also present. Johnson (1962) suggests that his Group I assemblage may be indicative of the presence of plants on a soft substrate.

The possible presence of algae and the dominance of low level filter feeders suggests a moderate turbidity akin to that of biofacies 3 (section IVB14) and it is thought that this facies may differ from biofacies 3 by a slightly greater degree of water movement.

**VB7 Biofacies 6**

Biofacies 6 is developed in all three columns. At Dunbar Works though occurring as high as 970 mm and 1110 mm it is largely confined to the basal zone between 3180 mm and 3720 mm below the top of the column. The Biofacies is well developed throughout the Skateraw column and in the Catcraig column below 210 mm from the top.

The fauna of this biofacies is apparently the least diverse in the shale (average number of species per level = 10.8, table 23), and it is likely that this is overestimated by the disarticulated or fragmented crinoids and bryozoa.

There are similarities between this fauna and the fauna of biofacies 4 and it is suggested that it developed under similar fairly turbid conditions. The reduction in the brachiopods is interpreted as the result of a slightly higher degree of water movement. The appearance of
the solitary crinoid *Ureocrinus bochschii* may be related to this increased energy, as may also be the occurrences of *Polidyovia attenuata* which is probably the deepest burrowing of the nuculid bivalves.

**VB8 Biofacies 7**

Biofacies 7 is only found at one point in the Dunbar Works column (3280 mm below the top) and at Skateraw is only developed towards the top of the Skateraw column (above 430 mm from the top). It is one of the characteristic Biofacies at Catoraig though as at Skateraw is best developed towards the top of the column (enclosure 1).

The faunal diversity of this Biofacies is relatively high (table 24) though it has most probably been overestimated by the inclusion of columnal and bryozan debris. The fauna is similar to that of Biofacies 5 though both vagile and sessile epifaunal filter feeders are slightly reduced. The gastropod fauna is also reduced and has changed in character with the disappearance of bellerophontids and the appearance of *Palaeozygoplena rugifera*. This is the only biofacies in which tabulate corals appear and in which nuculid bivalves are common.

Like biofacies 5 this is interpreted as being characteristic of an environment of moderate turbidity in which plants may have been able to develop. The environmental energy is however thought to have been higher causing a reduction in the number of epifaunal species and allowing the development of a few infaunal filter feeders.
(Lingula mytiloides) and of the fairly deep burrowing and mobile Polidavina attenuata. The occurrence of the tabulates may also be due to this greater amount of current activity which would have helped to keep visceral disc surfaces clean.

**VB9 Biofacies 8**

Biofacies 8 is a minor biofacies of the mudstone and only develops once in both Skateraw (330 mm) and Dunbar Works (930 mm) columns. At Catcraig it is more frequent with occasional developments in the column below 190 mm from the top (enclosure 1).

The fauna of this biofacies (table 25) is similar to those of biofacies 6 and 7 and also to some extent to that of biofacies 5. As in these biofacies the diversity is probably overestimated by the inclusion of columnals and bryozoan fragments. The low level epifaunal filter feeders are least well developed in this facies but there is no obvious replacement of this feeding group by other trophic levels. This is interpreted as the most hostile environment of the mudstone combining the effects of high turbidity as in biofacies 6 with the high energy effects of biofacies 7.

**VC) Biofacies Patterns**

The variation in biofacies throughout the three columns is depicted graphically in enclosure 1, and the subjective interpretation of cryptic faunal variations is generally substantiated. Despite this level to level variation an overall trend from high to low turbidity environments
can be seen from the base to the top of the Dunbar Works column. There seems also to be a trend towards greater environmental stability as one ascends this sequence. There is however a marked deviation from the trend between 870 and 1030 mm below the top where markedly more turbid and turbulent conditions prevailed for a time.

The Skateraw and Catcraig sequences show fluctuations of high to moderate turbidity combined with high to moderate turbulence and appear to become more stable towards the top of their successions though there is no apparent environmental trend. Both sequences show a marked deviation in the biofacies pattern towards an apparently low turbidity and low energy biofacies (biofacies 2) a short distance below the top of the column (Skateraw 270 mm, Catcraig 170 mm).

In all three columns the marked fluctuation in the environment separates the upper rather stable parts of the sequence from the lower more variable parts of the succession. It is suggested that these fluctuations can be correlated with each other and that the apparently low energy levels of the Skateraw and Catcraig deviations are spurious artifacts resulting from the high energy of this fluctuation which in its initial stages washed biofacies 2 shells down from the bank into the off bank areas. This might suggest that the fluctuation was caused by an increased strength in the SW to SSW current. It does not seem possible to devise a more refined correlation of the three successions.
The fossil orientation data which suggested that Dunbar Works had a generally lower environmental energy than Skateraw or Catcraig seems to be confirmed in the biofacies patterns. However the orientation data suggested that Skateraw had a more energetic environment than that at Catcraig which seems to contradict the biofacies interpretations. Skateraw lies much closer to the bank areas than does Catcraig (fig 9 - 11) and it is suggested that there is a general infiltration of shell fragments from the bank into this area causing a reduction in the energy levels inferred.

The biofacies patterns clearly give a much more complex and detailed picture of the mudstone than the simple picture inferred from the lithofacies and a much fuller depositional history can now be deduced (see section VI). The failure of the biofacies to distinguish the basal shaly lithofacies of the Skateraw and Catcraig successions is undoubtedly due largely to their small representation in the association analysis (15 levels). Coupled with this is the fact that subjectively important faunal features of these beds are only weakly represented or not represented in the association analysis. The presence of Pliochonetes sp, Schuchartella fasciata and Rugosochonetes speciosus and the fact that this was the only level at Skateraw at which cups of Platycrinites conglobatus were found (supplementary collection) are features reminiscent of the upper parts of the Dunbar Works sequence and of the Skateraw Upper Limestone at Dunbar Works. The Skateraw and Catcraig sequences may thus have been initiated by a phase of high to moderate energy combined with low to moderate turbidity.
VI PALAEOENVIRONMENTAL SYNTHESIS

VIA) Introduction

The sections discussing the sedimentary petrology (section III), palaeoautecology (section IV) and palaeosynecology (section V) have all revealed details of the environments which prevailed during the deposition of the mudstone and of the Skateraw Upper Limestone and the purpose of this section is to discuss these environmental conditions further and to provide a detailed history of the formation of the mudstone and Skateraw Upper Limestone.

VIB) Environmental Factors

VIB1 Depth

Elucidation of the depth of deposition has been one of the major goals of a great deal of palaeoecological work yet depth itself is really a dimension of the environment rather than an environmental factors. However knowledge of the depth of deposition has such a strong bearing on the evaluation of a variety of environmental factors that consideration of this feature is appropriate.

There have been many indications in the palaeoautecological accounts that the strata were deposited in shallow water. An upper limit of 35 m is suggested by the occurrence of fenestellid and cryptostome bryozoa (section IV£) though the depth may have been as shallow as 14 m (E).
punctatus, IVH34) or even 7 m (C. sublaznellosa, IVH34). A lower depth limit of perhaps slightly more than 50 m is suggested by the coral faunas (section IVB) though greater depths down to about 100 m would be acceptable (echinoids, IVL; bryozoa, IVE). The deeper depth statistic derived from the possible pogonophoran affinities of Serpulites carbonarius (IVF6) must be regarded as extremely dubious.

Another estimate of the lower limit of the probable depth of deposition can be obtained from the probable existence of algae within the area (sections IV, IVE, IVI, VB6, VB8). Under extremely favourable conditions photosynthesis may occur at depths as great as 150 m (Johnson 1957) but bearing in mind the probable turbidity of the environment (VIIA) a photosynthetic limit would probably be reached at considerably shallower depths.

Independent estimates of depth may be obtained by a consideration of the depositional history of the area following the formation of the Skateraw Upper Limestone. The clastic sequence between the Skateraw Upper Limestone and the Chapel Point Limestone (section IIB9) appears to represent the regressive phase of a cyclothem formed by the rapid encroachment of deltaic plains into the marine environment. The thickness of this sediment infill could be used as an indication of the depth of deposition though two other factors - tectonic history and compaction must also be considered. Contemporaneous subsidence or uplift will cause a biased estimate which must then be regarded as respectively a maximum or minimum estimate. There is no evidence of uplift in the
Dunbar succession but its position on the edge of one of the depositional basins of the Midland Valley (Goodlet 1957) suggests that subsidence will have occurred. Moreover since sedimentation paused long enough for the development of the marine band with Spirifer it is likely that the time taken to fill the basin was long enough to allow considerable subsidence to take place. The second factor results from the fact that the shaly parts of the sequence have been compacted and is complicated by the fact that some compaction due to the weight of overburden will have occurred during the infill of the basin. Even neglecting this last factor decompaction of the sediment pile using compaction factors of 4.5 to 8 as deduced by Ferguson (1963) indicates that the estimates of maximum possible depth of the basin are in the order of 65 to 100 m which accords well with the fossil evidence.

Similar arguments may be applied to estimate the maximum possible palaeorelief within the area and using the compaction factor of 5 deduced from the Zoophycos laminae (section IVP3) it appears to have been in the order of 20 m. Using the maximum compaction factor of Ferguson (1963) a maximum palaeorelief of up to 30 m might be indicated. There is no evidence that these depth differences were over a critical factor in the control of biofacies.

VIB2 Temperature

The great diversity of the mudstone fauna and of most of the component groups is suggestive of tropical to sub-tropical shallow seas (Thorson 1957) and this is the sort of temperature environment
indicated by the corals (IVD). Modern sub-tropical to tropical waters range in temperature from 15° to 30° C (Hedgepeth 1957) but it is unlikely that the upper limit would be reached at any depth below the surface and at the depths indicated (VIB) the temperature range would probably be in the order of 12 to 26° C. On the basis of the corals (IVD) it is possible that a narrower possible range could be defined as 16 to 26° C.

The tropical to sub-tropical conditions inferred agree with the near equatorial position of Britain during the Carboniferous deduced from palaeomagnetic data (Irving 1964).

VIB3 Water movements

Azimuthal orientation data (sections IVD, IVH, IVM) indicate the presence of two current systems - one from the east to south east and one from the south to south west - though there are some ambiguities. These currents lie approximately parallel to or normal to the elongate trend of the bank, and there is evidence (IVH1) to suggest that the SW current was a stronger though perhaps less persistent current than the SE current.

In the interpretation of the biofacies great importance has been laid on the current strengths or energy of the environment but it is rather difficult to quantify the relative terms of high, moderate and low which were used. The high net accumulation of clays in the Dunbar Works and bank areas indicates generally low current speeds which even allowing for possible flocculation of particles must have been normally
less than about 3 cm/sec (Hjulstrom 1953). Movement and orientation of shells (or shell models) appears to begin at velocities of about 10 to 25 cm/sec (Brenchley and Newall 1970, Brill 1969, Schwarzacher 1963, Cain 1968, Menard and Boucot 1951) and the disarticulation of shells and orientation of shells and valves indicate the occasional development of such current strengths. Velocities of this order would probably be able to erode flocculated accumulations and produce deflationary layers of shell fragments but unflocculated clays would require speeds in the order of 100 cm/sec (Hjulstrom 1953).

The higher energy environments of the off bank areas at CatCraig and Skateraw with their associated slightly higher convex-up shell ratios may thus indicate that current speeds in the order of 12 to 25 cm/sec were common. The above figures may thus be used as a first approximation in defining biofacies energies as - low = less than 3 cm/sec, moderate = 3 - 10 cm/sec and high = 10 - 25 cm/sec.

The sediment which forms the mudstone sequence was probably introduced by one or both of the currents which have been recognised but its provenance is not clear. The asymmetrical cross-section of the banks might suggest a south westerly source. Parts of the Southern Upland Massif are thought to have persisted as small land masses into late Visean times (George 1960) and further to the south near Girvan appear to have acted as a source of sandy material (Goodlet 1957). Such current orientations as are available from the Skateraw Middle Limestone (section II, fig 8) indicate the presence of an easterly current but a south to south
westerly current appears to have been absent. The appearance of such a current may be related to the drowning of one of these relict areas, which had previously acted as a barrier. The clays of the mudstone might also have been winnowed off the surface of this shallow area.

On this interpretation the shale band within the North Greens Limestone of Midlothian and perhaps also that above the Charlestown Main at Invertiel could be derived from the same source and these muds probably interfingered north into the prodeltaic fans of the delta which eventually advanced south into the Dunbar area.

Alternatively the clastic sediments could all have been derived from a delta lying to the north and east and have been introduced into the area rather circuitously by the east to south east current.

The origin of the currents is not certain. According to Selley (1968) perpendicular bimodal azimuthal orientations might be produced by seaward flowing currents alternating with longshore drift. This does not seem applicable to the present situation where the major landmass probably lay to the north (Greensmith 1966) but the south east current might represent a long shore current. Palaeomagnetic data (Irving 1967) suggest that at this time Dunbar lay to the south of the palaeoequator in what from present day circulation patterns was probably the belt of south easterly trade winds though these would have blown from a direction that is at present the south. The south to south west current may thus have been a wind driven current. It must however be noted that the distribution
of volcanic ashes round the Lower Carboniferous volcano of Arthur's Seat suggest a northerly wind (Black 1966).

**VIB1: Illumination and Turbidity**

The probable depth of deposition and the possible existence of algae (section VIB1) indicate that the depositional sites lay within the photic zone. The actual levels of illumination would however have been controlled to a large extent by the turbidity of the environment and this is a factor which is believed to have had an important bearing on the development of the biofacies (section VB).

Quantification of the relative terms which were used, i.e. high, moderate and low, is however impossible as not only the turbidity of the bottom waters but also that of the whole water column must be considered. The possible occurrence of algae in biofacies 5 and 7 (sections VB6 and VB7) suggests that these biofacies of supposed relatively moderate turbidity were receiving at least 1% of the surface illumination and it is possible that in the biofacies of supposed higher relative turbidity the illumination was sufficiently reduced to preclude the growth of algae.

**VIB5: Substrate**

The substrate during the deposition of the mudstone was clearly mud with occasional shells and shell fragments. The firmness of this substrate however probably varied with facies from relatively firm in the low turbidity environments to very soft in the high turbidity -
low energy environments. The nature of the substrate in the high
turbidity high energy environments would probably be fairly firm.

Great importance has been attached by Wilson (1966) to the
efficacy of the softness of the substrate in controlling bottom communities
in the Neilson Shell Bed of the Central Coalfield and Fife but, though
its importance should not be underrated, it is thought that at Dunbar
its effects are secondary to those of turbidity and environmental energy.

The substrate of the Skateraw Upper Limestone at Dunbar Works
must have been firm and generally dominated by crinoidal and other
shell debris. At the other localities this shell material would have
been less dominant though the substrate was probably still firm.

VIB6 Rate of sedimentation

The abundant occurrence of erect rigid bryozoan colonies is
by analogy with the Rhone delta (Lagaaij and Gautier 1965) indicative
of sedimentation of rates of less than 1 cm/year. In fact sedimentation
was probably considerably slower and Schopf (1969) would interpret these
bryozoans as indicating sedimentation rates of less than 10 cm / thousand years.
The reduction in bryozoans and other filter feeders towards the base of the
Dunbar Works column may indicate somewhat higher deposition rates.

Using this figure as an average the mudstone could be interpreted
as having formed within 15,000 years and the overall history of the bank
complex including the Skateraw Upper Limestone might thus have taken
place in a time span of the order of 100,000 years.

VIB7 Salinity

The abundance and diversity of corals, brachiopods and crinoids (sections IVD, IVH, IVM), most modern species of which have little or no tolerance of brackish or hypersaline environments, suggests fully marine conditions. The salinity may thus have lain close to the present average of 35 parts per thousand.

VIB8 Oxygen content

The occurrence in each biofacies of sessile epifaunal species which must have lived on or close to the sediment surface indicates that the environment was always well aerated. Within the sediment however the occurrence of pyrite indicates that reducing conditions must have prevailed. An upper surface oxidised layer of sediment probably existed but its thickness cannot be estimated. The relative scarcity of muculid bivalves may indicate that the layer was generally thin but this does not seem to have inhibited the other infaunal deposit feeding groups now represented by their abundant traces (see also section VIB9).

VIB9 Food

The fauna of the mudstone is rather surprising in that it is dominated by epifaunal suspension or filter feeders though in modern muddy sediments...
deposit feeders are normally most abundant (Sanders 1956). Not only are the filter feeders abundant and diverse but a well stratified system can be recognised. This might imply the abundance of suitable food sources utilisation of which have enabled the filter feeders to exclude the deposit feeders at least as long as there is not a high turbidity. The function of the two currents over the bank area (see section VIC) might well have provided and maintained a supply of food for the filter feeders.

VIC) Generation of the bank

Bank-like bodies of similar relief and shape to the Dunbar bank are well known in modern shelf areas but are composed of sand or carbonate and no modern mud analogue has been found.

Sand banks are well known in the Southern North Sea (Houbolt 1968) where they are forming due to tidal currents and similar bodies elsewhere (Guilcher 1958) appear to have the same origin. Since tidal currents have not been recognised at Dunbar a process of this type seems unlikely especially as the hydraulic properties of clay particles are so markedly different from those of sand (Hjulstrom 1953).

The topic of submarine carbonate mud banks has recently been discussed by Bathhurst (1971) and it is clear that they are essentially self supporting systems produced and stabilised by algae and marine grasses. Though the presence of algae has been postulated they appear to have been best represented in biofacies which have only minor
developments in the bank area. It has however been suggested that in the past this role may also have been played by bryozoa (Pray 1958) or crinoids (Stockdale 1931). While the Dunbar crinoids and bryozoa would probably have had baffle type effects their disarticulated and fragmented preservation does not suggest that they could have had a sufficiently strong stabilising effect. Moreover the abundance of these groups is reduced near the base of the Dunbar Works succession yet it was at this point that the bank was being initiated.

The only alternative seems to lie in the rather peculiar hydrodynamic conditions of the area. The convergence of two currents must have set up a sheer zone of generally low velocity currents and it is suggested that beneath this zone a relatively high net accumulation was permitted.

**VID Palaeoenvironmental History**

The carbonate deposition of the Skateraw Middle Limestone was terminated by an influx of fine clastic material. These clastics are thought to have been carried in by a south to south westerly current the entry of which may have been permitted by the drowning of a low south westerly land mass, and the clay material may have been reworked from this area.

For a short time deposition was relatively slow perhaps due to residual barrier effects from the shoal area to the south west. As a result shale successions developed in the north east of this area but round Dunbar Works where there was the locus of a low current velocity
shear zone at the convergence of the south westerly current with an east to south east current deposition was higher and an elongate positive feature developed. The amount of sediment introduced soon increased perhaps due to increased submersion of the former land area allowing the south westerly current a greater freedom of access to the Dunbar area and mudstone sequences were initiated even in the north east of the area. Fluctuations in the relative strengths of these two coincident currents caused variations in the locus of the shear zone and in the amount of sediment reaching the area. The gradual depletion of the sediment source caused a gradual decrease in the turbidity experienced in the bank area which had continued to develop under the shear zone but immediately to the north of the bank development turbidity remained high to moderate perhaps due to material spilling down off the bank and being scoured by the stable south easterly currents and this phenomenon probably extended to affect areas northwards and further away from the bank.

The double current system had evidently created and maintained an abundant food supply and encouraged the growth of filter feeding organisms though these were generally somewhat inhibited at the times of highest turbidity. As the turbidity of the environment decreased increasingly more complexly stratified filter feeding associations developed.

A marked deviation from the general trend occurred late in the depositional history of the mudstone and for a while more turbulent and turbid conditions prevailed. This is reflected in the north easterly off bank areas by the introduction of material washed down from the pre-existing
low turbidity bank facies.

Following this short phase the sediment load became highly reduced and generally low turbidity conditions prevailed on the bank, though continued wastage caused moderate turbidities in the areas to the north. The apparently greater stability of this depositional phase may be a reflection of the absence of great fluctuations in the sediment load.

Eventually the sediment load became so reduced that deposition became minimal apart from the addition of bioclastic material and in probably fairly high energy conditions the lower bioturbated sideritic parts of the Skateraw Upper Limestone formed with their upper surface marking a distinct period of non-sedimentation.

With a reduction in the energy of the environment some clastic deposition occurred but renewed deposition was predominantly of carbonates which now form the upper parts of the Skateraw Upper Limestone. In the bank area these carbonates are largely bioclastic and derived from the local abundant crinoid-brachiopod fauna but in the areas to the north bioclastics are less prominent and were probably derived from the bank.

The final phase of the history of the bank developed when the supply of sediment finally ceased and permitted the growth of Lithostracion on the top of the bank. The continued evolution of this clastic free phase was however never permitted due to the area being swamped with a new influx of clays which were probably derived from a deltaic area to the
north and east.

VIE) **Implications**

The ability to recognise the geometry and nature of the bank arises from a fortuitous combination of sedimentary and tectonic histories. Had the Skateraw Upper Limestone not developed then the mudstones would have been virtually indistinguishable from the overlying prodeltaic sequences and the fossils might merely have suggested a greater persistence of life in one part of the area. Had the area been more deformed than the ability to infer a palaeorelief might also have been lost and a small basinal structure postulated. Such circumstances cannot be expected to accompany other similar occurrences and great care should be taken in discussing the origin of fossiliferous shales of variable thickness.

Secondly although the current regime deduced may be rather unusual the results do suggest that great care should be taken in analyzing the origin of other clastic or carbonate mud banks before an organic cause is accepted.
VII CONCLUSIONS

The lithology and fauna of the mudstone and Skateraw Upper Limestone are believed to have been controlled by the interaction of two current systems and by the availability of fine clay sediment.

The collision of a fluctuating sediment bearing south to south westerly current with a more stable sediment free east to south easterly current created a zone of low current velocities beneath which a mud bank feature developed. As the sediment load decreased a transition took place to carbonate deposition.

A rich supply of food from these currents favoured the growth of filter feeding organisms which though at first rather inhibited by the high quantities of sediment ultimately achieved a highly diversified and structured community, on the bank areas.

The dead shells of these organisms became to various degrees disarticulated and orientated and limited amounts of transport off the bank occurred.
This topic was suggested by Professor G. Y. Craig and Dr. W. B. Heptonstall and supervised by Dr. W. B. Heptonstall and I am extremely grateful to them both for their invaluable advice, assistance and discussion at all stages of this work. I would also like to thank Professor F. H. Stewart and Professor G. Y. Craig for allowing me the use of facilities in the Grant Institute of Geology during my study. I am also greatly indebted to Professor M. R. House, Department of Geology, University of Hull, for his encouragement and for the freedom he has allowed me in the use of facilities within his department.

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I would also like to thank my wife for the help and support which she has given to me at all stages in the work.
The fauna of the mudstone and Skateraw Upper Limestone contains many species worthy of systematic description or redescription but unfortunately the material available does not always warrant such a step. In this section five species are described. One of these descriptions is a redescription of a previously described species, Lepidesthes caledonica Jackson, based on new evidence as to its character. The other four species are new to science but only two, Lepidesthes cloughi sp. nov. and ?Ptiograptus dunbarensis sp. nov., have been named.

Unless otherwise noted all the specimens used in these descriptions are derived from the mudstone lying between the Skateraw Middle and Upper Limestones at Dunbar Works (NT 704761). The horizon is of Lower Limestone Group age (Late Viséan, $P_2$).
SYSTEMATIC DESCRIPTIONS

Phylum COELENTERATA
Sub-phylum CNIDARIA
Class HYDROZOA
Order HYDROIDA

Hydroid sp

Fig 36

Material - MAW, DW, E21(c7), .E48(d1), .E61(b2), .E61(c3), .E70(d5-9), .P11(g7-8).

Description

Small black chitinous tubes found encrusting bryozoan fragments (fig 36A), crinoid columns and the internal and external surfaces of brachiopod shells (fig. 36B). The flexuous tubes are branching (Fig 36B) and may cross each other (Fig 36B) or coil upon themselves (Fig 36A). Though essentially parallel sided the branches vary in width from .06 mm to .25 mm. No marked constrictions or swellings have been observed.

Discussion

The same or a similar species has been recorded from Woodend Quarry in Fife and was encrusting crinoid columns (Etheridge 1880).
Etheridge (1880) suggested that it might be an encrusting worm (Serpula sp) but specimens cleared in Schultze's solution give no indication of skeletal structure and reference to the hydroid coelenterates is preferred. The tubes appear to represent an encrusting hydrosome but as thecae have not been recognised a generic assignment cannot be made. The hydrosome characters differ only in the absence of swellings from those of Epallohydra adhaerens Kozlowski (Skevington 1965) but these characters might be expected in any encrusting hydroid. There is also a strong resemblance to species of Chaunograptus (Ruedemann 1947) which have recently been suspected of having hydroid affinities (Bulman 1970).

Stratigraphic Note

This appears to be the only hydroid to have been recorded from the Carboniferous though specimens of the supposed pterobranch Rhabdopleura delmeri Mortelmans (Mortelmans 1955) show no skeletal structure and might thus represent a hydroid.

Phylum ECHINODERMATA
Subphylum ECHINOZOA
Class ECHINOIDEA
Subclass PERISOECHINOIDEA
Order ECHINOCYSTITICOIDEA
Family LEPIDESTHIDAE
Genus LEPIDESTHES

Lepidesthes caledonica Jackson

Figs 37 - 40

1912 Lepidesthes caledonica - Jackson, p. 132

- 164 -
Figured material - MAW. Dw. F61(b1 - 8).

Other material - MAW. Dw. AZ, Ah6(a), D35, Dh2, Dh5, Dh6(bk - 3), D56(b2), D66, E21(f6 - 9), E48(b7 - 13), E51 (m2, l, c), F11(s2).

Description

The test shape and number of columns per ambulacrum or interambulacrum are unknown. Jackson (1912) indicated that there were at least 4 ambulacral columns and the variety of shape shown by the ambulacral plates supports this (fig 37, 38). The adradial columns were composed of transversely elongate plates (Fig 37) while the perradial plates were more equilateral and were commonly chevron shaped (fig 37, 38). The plates imbricate strongly and suture surfaces are non-planar and pitted (fig 38). Pore pairs are D-shaped surrounded by an indistinct peripodia and sited adorally on the plates. The plate surface is ornamented by low secondary tubercles with an indistinct scrobicule (fig 38). The extra-scrobicular surface has a granular ornament (fig 38). The internal surface of ambulacral plates is smooth though a low protuberance is developed between the pore pairs (fig 37). The pore pairs are occasionally surrounded by a shallow depression but this is believed to be a compactional feature.

The interambulacral plates have a similar ornament to the ambulacral plates (fig 39). They are generally oblong in shape and where elongation has occurred this is in the interradial plane (fig 39 E, F).
The spines are small, longitudinally striated and expanded at
the base.

The lantern is of aulodont type. The sides of pyramids are
grooved for the attachment of the interpyramidal muscles (fig 40C)
and the foramen magnum is shallow (fig 40A). The teeth are narrow,
short, grooved and sharply pointed (fig 40B). The brace is slender
and oblong (fig 40D). Traces of epiphyses can be seen attached to the
pyramid (fig 40A) but their nature is obscure.

Discussion

The non planar nature of the sutures suggests a rigid test during
life (Kier 1958).

Stratigraphic Note

This species has now been found at the following localities all
of which lie at or immediately below the position of the Neilson
Shell Bed: Roscobie (type locality, Jackson 1912), Dunbar Works (mudstone
and Skateraw Upper Limestone), Skateraw (mudstone and Skateraw Middle
Limestone (bed a)), Catcraig (mudstone and Skateraw Middle Limestone
(bed a)), Invertiel (author's collections).
Lepidesthes cloughi sp. nov.

Figures h1 - h9

Holotype
MAW. DW. F61(d) (figures h1 - 59)

Paratypes

Diagnosis
Species with prominent tubercles on plates, internal spines on adoral ambulacral plates and serrated teeth.

Description
The test shape and the number of columns per ambulacrum or interambulacrum are unknown.

Ambulacral plates are irregular in shape and imbricate strongly with non planar pitted sutural surfaces (fig h1, h2). Pore pairs are D-shaped and situated adorally within a distinct peripodia. Plate surfaces are ornamented with secondary tubercles which have a marked scrobicule though the number and size of the tubercles varies from plate to plate (fig h1). The extra-scrobicular surface has a granular appearance resulting from a coarse stereom structure. Internal surfaces of ambulacral plates are generally smooth except for a prominent protuberance between the pore pairs (fig h3). Some small elongate ambulacral plates carry a stout internal spine (fig h4).
Interamulacral plates are irregularly shaped and similarly ornamented to ambulacral plates (fig 45 - 47). Internal surfaces of interambulacral plates often carry a shallow subcircular depression and this is believed to result from the effects of compaction acting on the coarse stereom.

The spines are small, short and have an expanded base.

The lantern is of aulodont type. The pyramids are wide with a shallow foramen magnum. Pyramid sides are grooved for attachment of the interpyramidal muscles and pitted for attachment of the epiphyses (fig 48). The epiphyses are like-wise pitted on the attachment surface and the adradial surface of the free cupped portion is grooved for muscle attachment (fig 49C). The brace is stout and flat (fig 49A). The teeth are broad, grooved, longitudinally striate and have a blunt serrated point.

Discussion

The non-planar sutural surfaces indicate that the test was rigid during life (Kier 1958).

The spines on the internal surface of some ambulacral plates are interpreted as the last vestiges of an internal enclosure to the water vascular system and are homologous to similar spines in Hyattechinus (Jackson 1912, Kier 1965). Like those of Hyattechinus the spinose ambulacral plates are probably adoral plates.
The serrated teeth of *L. cloughi* are very similar to teeth illustrated by Kier (1965) but differ from the serrated teeth of the closely related genus *Meekechinus* which are flat tipped and spade-like. Etheridge (1873) has noted the occurrence of two types of echinoid teeth, simple, pointed and serrated, in the Scottish Carboniferous but as slightly differently shaped serrated teeth have been found associated with *Archaeocidaris* plates and spines (author's collections) it seems likely that at least one other species of the Scottish Carboniferous echinoid fauna also possessed serrated teeth. The problem of how the serrated point was grown and maintained is difficult to reconcile with the cone-in-cone growth of modern echinoid teeth (Markel 1970) and the structure of these Carboniferous teeth may have been somewhat different.

**Affinities**

This species appears to be quite distinct from other species of *Lepidesthes* and perhaps the species which superficially must closely resembles it is *Lepidesthes grandis* Kier (Kier 1958). In *L. grandis* however the pore pairs are situated aborally on the ambulacral plates.
Order: DENDROIDEA
Family: DENDROGRAPTIDAE
Genus: PTIOGRAPTUS Ruedemann 1908

**Ptiograptus? dumbarense sp. nov.**

Figs 50 - 54

Holotype: MAW. IN. A7 (figs 52, 53A).


**Diagnosis**

Rhabdosome ?flabellate with long (17 mm +) stem; mesh generally spreading and fairly regular except on lateral margins; stipes .36 - .20 mm (av. .50 mm) wide, 6 - 10/cm; dissepiments .16 - .40 mm (av. .26 mm) wide, 1 - 3/cm; stipes 'ropy'; autothecae 17 - 18/cm, denticulate, slightly introverted.

**Description**

No complete rhabdosomes have been found and the largest fragment (fig 52A) has an axial length of 60 mm + and a maximum breadth of 60 mm. All specimens are essentially planar and this together with the spreading mesh is thought to indicate that the rhabdosome was flabellate. The initial parts of the colony have not been certainly recognised though
one specimen (fig 52B) shows a rhabdosome fragment which bears short lateral branches and whose width varies from .66 mm to .74 mm (av. .72 mm). The proximal part of this 'stem' is broken and no surface of attachment has been seen.

The mesh is open and fairly regular with a generally spreading appearance (fig 50A, 52, 53). There are 6 - 10 stipes / cm (av. 8, table 26) and the stipes are generally subparallel and evenly spaced (table 27). Stipe width is rather variable ranging from .36 mm to .90 mm (av. .58 mm, table 28) but this may be partly due to compaction. The dissepiments number 1 - 3 /cm (table 29) but are very unevenly spaced (table 30) and their angle to the stipe is variable. They range in thickness from .17 mm to .42 mm (av., .26 mm, table 31) and are only slightly expanded at the base (fig 50, 51). Branching is generally dichotomous at a moderately high angle (c. 60°) and the branches quickly bend to become subparallel (fig. 50). In a few specimens (fig 52C, D, 53A), believed to represent lateral portions of the rhabdosome, the mesh is less regular and there is a tendency towards lateral branching and reflexing of the stipes. No anastomoses have been observed.

Several specimens (fig 51B, 54A) have stipes preserved in semi-relief by an infilling of pyrite and thecal tubes can be observed though it has proved impossible to work out details of thecal development. Autothecae have only been seen on the holotype (fig 52A) where a mould of a stipe shows a series of 6 thecae in profile. The denticulate free portions of two of these thecae are preserved and the free walls make
an angle of 30 to 35° with the stipe axis while the slightly introverted apertural margins make an angle of 75 - 80°. Five autothecae occupy the space of 2.52 mm (i.e. 17 - 18/cm). Bithecae have not been recognised. Occasionally on fully compressed stipes a low narrow (0.05 mm wide) ridge may be seen and is believed to be the expression of the internal sclerotised stolon system.

Discussion

The mesh is similar to both Dictyonema and Ptyograptus and generic assignment depends on the rhabdosome form (Bulman 1938, 1970; Ubaghs 1941). This feature is not preserved but the evidence favours a flabellate form and the species has accordingly been tentatively placed in Ptyograptus. Thecal details of Ptyograptus are not known though the genus may be heterogenous in this respect (Ubaghs 1941). The 'ropy' stipe appearance of the present species may be due to an elongate thecal structure similar to that which characterises the subgenera Dictyonema (Pseudodictyonema) and Callograptus (Pseudocallograptus) (Skevington 1963, Boucek 1954, Bulman 1970). The same structure may be present in Dendrograptus (Stelechocladia) and Desmograptus (Syrrhipidograptus) (Bulman 1970).

Affinities

Ptyograptus dumbarrense sp. nov. and another Carboniferous dendroid P. fourniri Ubaghs (Ubaghs 1941) are extremely alike. The stipes of P. fourniri Ubaghs are slightly narrower (.3 - .35 mm) than, but of similar frequency (8 - 10/cm) to, those of P. dumbarrense sp. nov. while
the dissepiments are more frequent (3 - 5/cm) though of similar width (.25 - .3 mm). The autothecae of P. fourniri Ubaghs are less frequent (1h - 17/cm) but appear to be denticulate and slightly introverted like those of P. dunbarensense sp. nov. The abrupt stipe dilations found in P. fourniri var. (Ubaghs 1941) have not been seen in the present species.

The similarity of these two species is emphasised by their dissimilarity to other Carboniferous dendroids with a Dictyonema-type mesh. The two species of Dictyonema, D. ultimum Ubaghs and D. fraiponti Ubaghs, associated with P. fourniri Ubaghs have more crowded meshes and fewer autothecae than P. dunbarensense sp. nov. (Ubaghs 1941). Four species of Dictyonema have been recorded from the United States but all are more delicate than P. dunbarensense sp. nov. having harrower and more crowded stipes (Ruedemann 1947). Callograptus carboniferous Hind (Hind 1907) is only poorly known but can be differentiated from P. dunbarensense sp. nov. at least by its dissepiments which are regular and more frequent (h/cm) (Bulman in Ubaghs 1941).

Ubaghs (1941) has compared P. fourniri Ubaghs with Dictyonema perradiatum Ruedemann but this species is clearly different from P. dunbarensense sp. nov. as it has more numerous stipes (12 - 13/cm), dissepiments and autothecae (24 - 26/cm).

Stratigraphic Note

This is the first dendroid graptolite species to be described from the Scottish Carboniferous though they may also occur at the same horizon in Invertiel and at a lower horizon near Stirling (author's collections).
Bulman (1970) mentions as perhaps the youngest dendroid an undescribed species of Dictyonema from the Yoredale series of Yorkshire and this is reputed to be of E, age (Harland et al. 1967). This species is thus probably younger than the high P₂ species described here but the other Carboniferous dendroids which have been recorded are all apparently older than P. dunbarense sp. nov. — Callograptus carboniferous Hind (B₁ — S₂ — Hind 1907, Earp et al. 1961), dendroid of Callograptus sp. (C₂S₁ — Hudson et al. 1966), Desmograptus monensis Hind (P₁b — Hind 1907, Lewis 1930), Belgian dendroids (VIA(=C₂S₁) — Ubaghs 1941), American dendroids (Kinderhookian (= Tournaisian) — Ruedemann 1947).

Dendroid, genus and species indeterminate

**Fig 54B**

Figured material  W/23/27 (fig 54B)

Other material  W/25/27, W/25/28

**Description**

The largest specimen (fig 54B) is a horn shaped rhabdosome fragment with a curved length of 15 mm and a maximum width of 5 mm. Preservation of the stipes is very poor and fragmentary but at least eleven are present in 5 mm (22/cm) though the specimen is probably laterally compressed. The stipes (fig 54B) appear to be parallel and are narrow (.1h — .2h mm, av. .21 mm) and parallel sided. One dissepiment (width = .10 mm) has tentatively been identified but they appear to be rare. The stipes are all highly compressed and the autothecae and bithecae have not been observed.
Discussion

This species is clearly distinct from *P. dunbarense* sp. nov. on the basis of its narrower stipes but the lack of reliable information on its mesh and other characters precludes assignment of it to any genus or species.


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ETHERIDGE, R., 1876b. On an adherent form of Productus and a small Spiriferina from the Lower Carboniferous Limestone Group of the East of Scotland. Q.J.G.S., 32, 454 - 465


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FLETT, J. S., 1937. The First Hundred Years of the Geological Survey of Great Britain., H. M. S. O.


TABLE 1
Skateraw Middle Limestone Succession
(beds are lettered in descending sequence)

(a) **Echinoid Band**
Highly argillaceous bioclastic limestone with abundant plates of echinoids (*Hepidesthes caledonica*, *Archeocidaris urei*, ?*Melonechinus* sp.) and crinoids on its upper surface at Catcraig (50 mm) and Skateraw (90 mm). At Dunbar Works an unfossiliferous limestone (100 mm).
Average *0.08 m*

(b) **Saccaminopsis Band**
Recrystallised limestone, largely composed of coalescing lenses of *Saccaminopsis fusulinaformis*. Dunbar Works (0.14 m), Skateraw (0.5 m), Catcraig (0.49 m).
Average *0.18 m*.

(c) **Shale**
Dark, unfossiliferous. Dunbar Works (60 mm), Catcraig (100 mm), Skateraw (50 mm).
Average *0.07 m*.

(d) **Limestone**
Dunbar Works (0.32 m), Catcraig (0.08 m), Skateraw (0.10 m).
Average *0.17 m*.
TABLE 1 (Cont)

(e) **Limestone and Shale**

At Catcraig (0.18 m) and Skateraw (0.20 m) of limestone nodules in dark shale. At Dunbar Works nodular limestone (0.52 m).

*Average 0.30 m*

(f) **Shale**

Dark unfossiliferous. Dunbar Works (70 mm), Catcraig (60 mm), Skateraw (100 mm).

*Average 0.08 m*

(g) **Limestone**

Nodular limestone with shaly partings. Containing occasional brachiopod, gastropods and crinoid debris often with algal haloes. *S. fusulinaformis* rare. Dunbar Works (1.71 m), Catcraig (1.70 m), Skateraw (1.56 m).

*Average 1.66 m*

(h) **Shale**

Dark, fossil fragments, Dunbar Works (50 mm), Catcraig (20 mm), Skateraw (70 mm).

*Average 0.05 m*

(i) **Limestone**

Dunbar Works (1.06 m), Skateraw (0.83 m), Catcraig (0.70 m).

*Average 0.86 m*
<table>
<thead>
<tr>
<th>TABLE 1 (Cont)</th>
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</thead>
</table>

(j) **Shale**
Dark, Dunbar Works (10 mm), Skateraw (60 mm), Dunbar Works (10 mm).
**Average 0.03 m**

(k) **Limestone**
With rare Chaetetes. Dunbar Works (0.28 m), Skateraw (0.14 m), Catcraig (0.20 m).
**Average 0.21 m**

(l) **Shale**
Dunbar Works (20 mm), Catcraig (60 mm), Skateraw (60 mm)
**Average 0.05 m**

(m) **Limestone**
With Chaetetes sp., Zoophycos sp., large columnals. Dunbar Works (0.14 m), Catcraig (0.08 m), Skateraw (0.08 m).
**Average 0.10 m**

(n) **Shale**
Dunbar Works (10 mm), Catcraig (20 mm), Skateraw (50 mm)
**Average 0.03 m**

(o) **Limestone**
With Chaetetes sp., Gigantoproductid sp, Productid spp, Zoophycos sp., fish remains, large and small columnals. Dunbar Works (0.16 m), Skateraw (0.13 m), Catcraig (0.25 m).
**Average 0.37 m**
(p) **Limestone**

As above. Dunbar Works (0.60 m), Catcraig (0.28 m), Skateraw (0.24 m).

Average 0.311 m

(q) **Shale**

Crinoid columnals, *bänemetocrinus biserialis*, *Ureocrinus bockschii*, productid spp., *Spirifer trigonalis*, zaphrentid spp., fenestellid and ?trepostome bryozoa, *Weberides?* sp., *Archaeoidaris urei*, coal fragments. Dunbar Works (0.06 m), Catcraig (0.14 m), Skateraw (0.33 m).

Average 0.18 m
<table>
<thead>
<tr>
<th>Central Coalfield</th>
<th>West Fife</th>
<th>East Fife</th>
<th>Midlothian</th>
<th>Dunbar</th>
<th>Berwick on Tweed</th>
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<tr>
<td>Mid Hosie Lst.</td>
<td>L. Kinniny Lst.</td>
<td>Kirkby 14</td>
<td>U. Wexhim Lst.</td>
<td>Dryburn Ft. Lst.</td>
<td>?</td>
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<tr>
<td>Milngavie M.B.</td>
<td>Mill Hill M.B.</td>
<td>Kirkby 27</td>
<td>?</td>
<td>'Spirifer' band</td>
<td>unnamed lst.</td>
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</table>

White Lst.

**TABLE 3**

Faunal list for the mudstone and Skateraw Upper Limestone of Dunbar Works, Catcraig and Skateraw. The capital letters D, C & S indicate the three localities and the subscript S indicates that a species is only known from the supplementary collections. The subscript 1 is a reference to the Skateraw Upper Limestone.

<table>
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<tr>
<th>Phylum Protozoa</th>
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<tr>
<td>Foraminifera spp.</td>
<td>DS, SS, CS</td>
</tr>
<tr>
<td>Saccaminopsis fusulinaformis (M'Coy)</td>
<td>SS, CS</td>
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<table>
<thead>
<tr>
<th>Phylum Porifera</th>
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<td>Hexactinellid sp.</td>
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<td>Clionolithes sp.</td>
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<th>Phylum Coelenterata</th>
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<tr>
<td>Allotropiophyllum tuberculatum (Thomson)</td>
<td>D, CS, DL, Cl</td>
</tr>
<tr>
<td>Claviphyllum carruthersi (Hill)</td>
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</tr>
<tr>
<td>Claviphyllum eruca (M'Coy)</td>
<td>DL</td>
</tr>
<tr>
<td>Lithostrotion sp.</td>
<td>DL, SL</td>
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<tr>
<td>'Zaphrentis' constricta Carruthers</td>
<td>D, C, S, DL, Cl</td>
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<tr>
<td>'Zaphrentis' ?curvilinea (Thomson)</td>
<td>DL</td>
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<tr>
<td>Auloporoid sp</td>
<td>DL</td>
</tr>
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<td>Cladochonus crassus (M'Coy)</td>
<td>D, DS, DL</td>
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<tr>
<td>Emmensia aff parasitica (Phillips)</td>
<td>D, CS, S, DL</td>
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<td>Microcyathus cyclostomus (Phillips)</td>
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<tr>
<td>Hexagonaria marginata (Fleming)</td>
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<td>Taxon</td>
<td>Location</td>
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<td>----------------------------------------------------------------------</td>
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<tr>
<td>Hydroid sp.</td>
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<tr>
<td>Paracomularia tubericosta (Sandberger)</td>
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<tr>
<td><strong>Phylum Bryozoa</strong></td>
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<td>Fenestellid spp. indet</td>
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<td>Fenestella plebia M'Coy</td>
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<tr>
<td>Fenestella ?futex M'Coy</td>
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<td>Fenestella ?polyoporata (Phillips)</td>
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<tr>
<td>Fenestella ?bicellulata Etheridge</td>
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<td>Polypora dendroides (M'Coy)</td>
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<td><strong>Productoid sp 2</strong></td>
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</tr>
<tr>
<td>Orthocone nautiloid spp (Smooth)</td>
<td>D, C, S, Dl</td>
</tr>
<tr>
<td>Cyrtoceras rugosum (Fleming)</td>
<td>D, C, S</td>
</tr>
<tr>
<td>Reticycloceras sulcatum (Fleming)</td>
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<td>Orthocone nautiloid sp ornamented</td>
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<tr>
<td>Orthocone nautiloid sp. ornamented</td>
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<table>
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<tr>
<th>Phylum Mollusca - Gastropoda</th>
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<tr>
<td>Platyceras neratoides (Phillips)</td>
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<tr>
<td>Straporallus (Eumphalus) carbonarius (J. Sowerby)</td>
<td>D, C, S, Dl</td>
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<tr>
<td>Angynomphalus radians (de Koninck)</td>
<td>Ds, Ss</td>
</tr>
<tr>
<td>Naticopsis sp</td>
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<tr>
<td>Bucaniopsis roscobiensis Wier</td>
<td>Ds</td>
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<tr>
<td>Bucaniopsis decussatus (Fleming)</td>
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</tr>
<tr>
<td>Bucaniopsis tenuis Weir</td>
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</tr>
<tr>
<td>Euphemites urei (Fleming)</td>
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</tr>
<tr>
<td>Species</td>
<td>Distribution</td>
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<td>----------------------------------------------</td>
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<tr>
<td>Bellerophontid spp</td>
<td>D, C, S</td>
</tr>
<tr>
<td>Glabrocingulum atomarium (Phillips)</td>
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<tr>
<td>Platyconcha dunlopiana Longstaff</td>
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<tr>
<td>Hesperiella thomsoni (de Koninck)</td>
<td>D, S, C</td>
</tr>
<tr>
<td>Donaldina nana (de Koninck)</td>
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</tr>
<tr>
<td>?Anthinopsis sp</td>
<td>Ds, ?C</td>
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<td>?Hesperiella sp</td>
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<tr>
<td>Soleniscus sp</td>
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<td>Palaeozygopleura scalaroidea (Phillips)</td>
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<tr>
<td>Microptychius sp</td>
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<td>?Zygopleurid sp</td>
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<tr>
<td>Gastropod spp, indet</td>
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**Phylum Mollusca - Bivalvia**

<table>
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<tbody>
<tr>
<td>Cypricardella concentrica Hind</td>
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<tr>
<td>Cypricardella selysiana (de Koninck)</td>
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<tr>
<td>?Sanguinolites sp</td>
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<tr>
<td>Edmondia sulcata (Fleming)</td>
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<tr>
<td>Edmondia lyelli Hind</td>
<td>D³</td>
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<tr>
<td>Polidercia attenuata (Fleming)</td>
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</tr>
<tr>
<td>Nuculopsis gibbosa (Fleming)</td>
<td>Ds, Ss, C</td>
</tr>
<tr>
<td>Nuculana brevirostris (Phillips)</td>
<td>D, Ss, C</td>
</tr>
<tr>
<td>Palaeoneilo laevirostrum (Portlock)</td>
<td>D, C, S</td>
</tr>
<tr>
<td>Limpecten dissimilis (Fleming)</td>
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**TABLE 3 (Cont) (vi)**

<table>
<thead>
<tr>
<th>Invertebrate</th>
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<tbody>
<tr>
<td>Euchondria neilsopi Wilson</td>
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<tr>
<td>Pernopacten fragilis Wilson</td>
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<td>Posidonia corrugata (Etheridge)</td>
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<tr>
<td>Posidonia corrugata (Etheridge) var gigantea Yates</td>
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<tr>
<td>Pectenid sp. (smooth)</td>
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<td>Pectenid spp. indet</td>
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**Phylum Echinodermata - Echinozoa**

<table>
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<tr>
<td>Archaeocidaris urei (Fleming)</td>
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<tr>
<td>Lepideathes caledonica Jackson</td>
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<td></td>
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<tr>
<td>Lepideathes cloughi sp. nov.</td>
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**Phylum Echinodermata - Crinoidea**

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<tr>
<td>Potericrinites? magnus (Wright)</td>
<td></td>
<td>Dl</td>
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<tr>
<td>Phanocrinus calyx (M'Coy)</td>
<td></td>
<td>D</td>
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<tr>
<td>Phanocrinus? altus Wright</td>
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<td>Dl</td>
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<tr>
<td>Phanocrinus stellaris (Wright)</td>
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<tr>
<td>Phanocrinus gordoni Wright</td>
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<td>Fifeocrinus tielensis (Wright)</td>
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<td>Fifeocrinus tielensis (Wright) var</td>
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<td>Firthocrinus lepidus Wright</td>
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<tr>
<td>Camptocrinus compressus Wright</td>
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<tr>
<td>Caldenocrinus curtus Wright</td>
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<tr>
<td>Artichthycrinus springeri Wright</td>
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<td>Ds</td>
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<tr>
<td>Species</td>
<td>Abbreviations</td>
<td></td>
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<tr>
<td>Aphelecrinus dilatus Wright</td>
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<td>Talanterocrinus redesdalensis Wright</td>
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<tr>
<td>Rhodocrinus baccatus Wright</td>
<td>Dl</td>
<td></td>
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<tr>
<td>Rhabdocrinus scotocarbonarius (Wright)</td>
<td>Ds, Dl</td>
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<tr>
<td>Mespilorinus pringlei Wright</td>
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<td></td>
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<tr>
<td>Onychocrinus liddelensis Wright</td>
<td>Dl</td>
<td></td>
</tr>
<tr>
<td>Onychocrinus Wrighti Springer</td>
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<td></td>
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<tr>
<td>Pedinocrinus clavatus (Wright)</td>
<td>Dl</td>
<td></td>
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<tr>
<td>Scotiacrinus tyriensis (Wright)</td>
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<tr>
<td>Kalliomorphocrinus elongatus (Wright)</td>
<td>Ds</td>
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<tr>
<td>Kalliomorphocrinus scoticus (Wright)</td>
<td>Ds</td>
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<tr>
<td>Allagecrinus austinii Carpenter and Etheridge</td>
<td>Ds</td>
<td></td>
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<tr>
<td>Anemocrinus biserialis Wright</td>
<td>D, Dl</td>
<td></td>
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<tr>
<td>Amphiacrinus scoticus Springer</td>
<td>Dl</td>
<td></td>
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<tr>
<td>Urecrinus bookschii (Geinitiz)</td>
<td>D, C, S, Dl</td>
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<tr>
<td>?Cyathocrinites spq</td>
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<td>?Hydreionocrinus sp.</td>
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<td>Tyrieocrinus laxus Wright</td>
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<td>Dichocrinus of fusiformis</td>
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<td>Dichocrinus sp</td>
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<tr>
<td>Platycrinites conglobatus Wright</td>
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<tr>
<td>Platycrinites crassiconicus Wright</td>
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<td></td>
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<tr>
<td>Platycrinites spiniger Wright</td>
<td>D</td>
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<tr>
<td>Crinoid cup plates indet</td>
<td>D, Dl</td>
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<td>Phylum Echinodermata - Blastoeidea</td>
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<td><strong>Astrocrinus benniei</strong> Etheridge</td>
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<tr>
<td>Anomalocaris sp.</td>
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<thead>
<tr>
<th>Phylum Echinodermata - Asterozoa</th>
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<tr>
<td><strong>Onychaster flexilis</strong> Meek and Worthen</td>
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<table>
<thead>
<tr>
<th>Phylum Hemichordata</th>
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<tr>
<td><strong>?Ptiograptus dunbarense</strong> sp. nov.</td>
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<tr>
<td><strong>Dendroid</strong> sp.</td>
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<table>
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<th>Trace Fossils</th>
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<tbody>
<tr>
<td>Pyritised linear burrows</td>
<td></td>
</tr>
<tr>
<td>Pyritised sheet networks</td>
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<tr>
<td>Pyritised three-dimensional networks</td>
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<tr>
<td>Pyritised trace fossils?</td>
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<tr>
<td>Sideritised (Halo' burrows</td>
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<tr>
<td>Sideritised 'Chondritid' burrows</td>
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<tr>
<td>Zoophycos sp.</td>
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<table>
<thead>
<tr>
<th>Phylum Chordata</th>
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<tbody>
<tr>
<td><strong>Cladodus ?striatus</strong> Agaosiz</td>
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<tr>
<td><strong>Petalodus accuminatus</strong> Agaosiz</td>
<td></td>
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<tr>
<td><strong>Petalodus ?rectus</strong> Agaosiz</td>
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<tr>
<td><strong>Petalodus sp.</strong></td>
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<tr>
<td>Taxon</td>
<td>Location(s)</td>
</tr>
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<td>-------------------------------</td>
<td>-------------</td>
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<tr>
<td>Petalorhynchus psittacinus Agassiz</td>
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<tr>
<td>Ctenoptychius ?lobatus (Etheridge)</td>
<td>Dl</td>
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<tr>
<td>Ctenoptychius ?serratus Owen</td>
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</tr>
<tr>
<td>Myrhizodus sp</td>
<td>Ds</td>
</tr>
<tr>
<td>Psephodus magnus Agassiz</td>
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<td>Helodus sp</td>
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<td>Rhabdoderma sp</td>
<td>D, C, S</td>
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<td>Rhizodopsis sp</td>
<td>Ds, C, S</td>
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<tr>
<td>Megalichthys sp</td>
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Kingdom Plantae

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<th>Location(s)</th>
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<tr>
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<td>Ds</td>
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<tr>
<td>Plant remains indet</td>
<td>D</td>
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Z. constricta. Frequency distributions of apical orientation in the Dunbar Works, Catcraig and Skateraw Quarries.

<table>
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<tr>
<th>Class Median</th>
<th>Dunbar Works</th>
<th>Catcraig</th>
<th>Skateraw</th>
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<tr>
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<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>20°</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>40°</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
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<td>60°</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>80°</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>100°</td>
<td>0</td>
<td>4</td>
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<td>120°</td>
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<td>2</td>
<td>1</td>
</tr>
<tr>
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<td>0</td>
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<td>160°</td>
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<td>2</td>
<td>1</td>
</tr>
<tr>
<td>180°</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>200°</td>
<td>2</td>
<td>1</td>
<td>0</td>
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<td>220°</td>
<td>4</td>
<td>6</td>
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</tr>
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<td>240°</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>260°</td>
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</tr>
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<td>280°</td>
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<td>1</td>
</tr>
<tr>
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</tr>
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<td>340°</td>
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Microcyathus cyclostomus (Phillips). Frequency distribution of number of corallites per coralla at Skateraw and Catorcaig (column and supplementary collections).

<table>
<thead>
<tr>
<th>Number of Corallites</th>
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<th>Catorcaig</th>
<th>Total</th>
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<tr>
<td>0</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>9</td>
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Dithryocaris sp.  Mandible distribution
Catcraig, Skateraw and Dunbar Works (Column and supplementary collections).

<table>
<thead>
<tr>
<th>Mandibles</th>
<th>Catcraig</th>
<th>Skateraw</th>
<th>Dunbar Works</th>
<th>Total</th>
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<tbody>
<tr>
<td>Left</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Right</td>
<td>13</td>
<td>1</td>
<td>2</td>
<td>16</td>
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<tr>
<td>Total</td>
<td>19</td>
<td>5</td>
<td>4</td>
<td>28</td>
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TABLE 7

*Weberides mucronatus.* Orientation of glabellae and pygidia in the Dunbar Works, Catcraig and Skateraw columns.

A) Dunbar Works

<table>
<thead>
<tr>
<th>Level (cm.)</th>
<th>Glabellae Concave up</th>
<th>Glabellae Convex up</th>
<th>Pygidia Concave up</th>
<th>Pygidia Convex up</th>
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<tbody>
<tr>
<td>1 - 10</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>11 - 20</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>21 - 30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>31 - 40</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>41 - 54</td>
<td>-</td>
<td>-</td>
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<td>1</td>
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<td>75 - 84</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
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<td>85 - 94</td>
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<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>95 - 104</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>105 - 114</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>155 - 164</td>
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<td>3</td>
<td>1</td>
<td>1</td>
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<tr>
<td>165 - 174</td>
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<td>-</td>
<td>2</td>
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<td>185 - 194</td>
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<td>1</td>
<td>-</td>
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<td>4</td>
<td>2</td>
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<td>298 - 307</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>308 - 317</td>
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<td>1</td>
<td>2</td>
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### B) Catcraig

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TABLE 8

Eomarginifera longispina. Ventral valve and shell azimuthal and way-up orientation distributions. Dunbar Works Column.

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**TABLE 9**

Eomarginifera longispina. Ventral valve and shell azimuthal and way up orientation distributions. Catcraig column.

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TABLE 10

**Echinoconchus punctatus.** Orientation distribution shells (or ventral valves) and dorsal valves. Dunbar Works column.

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**TABLE II**

*Cleothridina sublamellosa*. Orientation distributions of shells and valves. Dunbar Works column.

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Crurithyris urei
Way-up orientation distribution of shells and valves in the Dunbar Works, Skateraw and Catcraig columns.

A) Dunbar Works

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### C) Catcraig

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<tr>
<td>340</td>
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<td>3</td>
</tr>
</tbody>
</table>
Tornquistia polita; Way-up orientation of shells and ventral valves Dunbar Works, Skateraw and Catcraig columns.

A) Dunbar Works

<table>
<thead>
<tr>
<th>Level</th>
<th>Concave-up</th>
<th>Convex-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>11 - 20</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>21 - 30</td>
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<td></td>
</tr>
<tr>
<td>31 - 40</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>41 - 50</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>51 - 60</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>61 - 70</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>71 - 80</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>91 - 100</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>101 - 110</td>
<td>33</td>
<td>16</td>
</tr>
<tr>
<td>111 - 120</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>121 - 130</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>131 - 140</td>
<td>4</td>
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<td>141 - 150</td>
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<td>3</td>
</tr>
<tr>
<td>151 - 160</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>161 - 170</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>171 - 180</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>181 - 190</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>191 - 200</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>201 - 210</td>
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<tr>
<td>211 - 220</td>
<td>6</td>
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</tr>
<tr>
<td>221 - 230</td>
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<td></td>
</tr>
<tr>
<td>231 - 240</td>
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<td></td>
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<tr>
<td>241 - 250</td>
<td>6</td>
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<tr>
<td>251 - 260</td>
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<td>261 - 270</td>
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<tr>
<td>271 - 280</td>
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</table>

Total    113         92
### TABLE 13 (Cont)

#### B) Skateraw

<table>
<thead>
<tr>
<th>Level</th>
<th>Concave-up</th>
<th>Convex-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>2</td>
<td>17</td>
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<tr>
<td>11 - 20</td>
<td>4</td>
<td>14</td>
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<tr>
<td>21 - 30</td>
<td>5</td>
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<td>31 - 40</td>
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<td>41 - 50</td>
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<td>51 - 60</td>
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<td>61 - 70</td>
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<td>71 - 80</td>
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<td>9</td>
</tr>
<tr>
<td>81 - 90</td>
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<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34</strong></td>
<td><strong>76</strong></td>
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#### C) Catcraig

<table>
<thead>
<tr>
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<th>Convex-up</th>
</tr>
</thead>
<tbody>
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<td>11 - 20</td>
<td>6</td>
<td>8</td>
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<td>21 - 30</td>
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<td>9</td>
</tr>
<tr>
<td>31 - 40</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>41 - 50</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>51 - 60</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>61 - 70</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>53</strong></td>
<td><strong>62</strong></td>
</tr>
</tbody>
</table>
### TABLE 1

Relationship between knowledge of the anal structure and the number of specimens examined in British Carboniferous inadunate crinoid species (based on Wright 1951 - 54).

A) Numbers of species

<table>
<thead>
<tr>
<th>Anal structure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>primitive</td>
<td>non-primitive</td>
</tr>
<tr>
<td>&lt;10</td>
<td>54</td>
</tr>
<tr>
<td>10-100</td>
<td>11</td>
</tr>
<tr>
<td>&gt;100</td>
<td>-</td>
</tr>
<tr>
<td>Specimens</td>
<td>Total</td>
</tr>
</tbody>
</table>

B) Percentages

<table>
<thead>
<tr>
<th>Anal structure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>primitive</td>
<td>non-primitive</td>
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<tr>
<td>&lt;10</td>
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<tr>
<td>10-100</td>
<td>9.0</td>
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<tr>
<td>&gt;100</td>
<td>-</td>
</tr>
<tr>
<td>Specimens</td>
<td>Total</td>
</tr>
<tr>
<td>Size (mm)</td>
<td>Cup Width</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>0 - 1</td>
<td>-</td>
</tr>
<tr>
<td>1 - 2</td>
<td>-</td>
</tr>
<tr>
<td>2 - 3</td>
<td>-</td>
</tr>
<tr>
<td>3 - 4</td>
<td>1</td>
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<tr>
<td>4 - 5</td>
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<tr>
<td>5 - 6</td>
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<td>11 - 12</td>
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</tr>
<tr>
<td>Level (cm)</td>
<td>Radials</td>
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<td>161 - 170</td>
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<tr>
<td>211 - 220</td>
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</tr>
<tr>
<td>Total</td>
<td>237</td>
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</table>
### TABLE 17

Platycrinites conglobatus. Basal circlet size frequency distribution Mudstone and Skateraw Upper Limestone Dunbar Works.

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
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</tr>
<tr>
<td>1 - 2</td>
<td>-</td>
</tr>
<tr>
<td>2 - 3</td>
<td>-</td>
</tr>
<tr>
<td>3 - 4</td>
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<td>4 - 5</td>
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<tr>
<td>5 - 6</td>
<td>18</td>
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<tr>
<td>6 - 7</td>
<td>22</td>
</tr>
<tr>
<td>7 - 8</td>
<td>47</td>
</tr>
<tr>
<td>8 - 9</td>
<td>60</td>
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<td>9 - 10</td>
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<td>10 - 11</td>
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<td>11 - 12</td>
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<td>12 - 13</td>
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<td>13 - 14</td>
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<tr>
<td>17 - 18</td>
<td>5</td>
</tr>
<tr>
<td>18 - 19</td>
<td>1</td>
</tr>
</tbody>
</table>
**TABLE 18**

Faunal Composition of Biofacies 1

A = abundant (100 - 80%); F = frequent (80 - 60%); C = common (60 - 40%)
S = seldom (40 - 20%); * = probably largely derived or exaggerated.

High level filter feeders: Crinoid spp. (A), *P. conglobatus* (A)
*Z. konincki* (C), *P. gordonii* (C), *P. crassiconicus* (C), Inadunate spp. (A).

Medium level filter feeders: Bryozoan spp. (A), Dendroid spp. (S)

Low level epifaunal filter feeders:
(1) sessile - *C. sublamellosa* (A), *E. longispina* (A), *S. carbonarius* (C)
*E. punctatus* (C), *B. scabricula* (C), *T. polita* (C), *G. ambiguus* (S),
*R. celticus* (S).

(2) vagile - Pectenid sp. (F), *P. corrugata* (S)

Herbivores and Omnivores: *L. caledonica* (C), Gastropod spp. (S)

Carnivores:
(1) sessile - *Z. constricta* (S)

(2) vagile - Orthocone nautiloid spp. (C), *Catastroboceras* spp. (C),
Cephalopod spp. (S).
<table>
<thead>
<tr>
<th>Deposit Feeders: 'Halo' burrow (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Total number of species in biofacies</em></td>
</tr>
<tr>
<td><em>Average number of species per level</em></td>
</tr>
</tbody>
</table>
**TABLE 19**

Faunal Composition of Biofacies 2

Lettering as in table 18.

High level filter feeders: Crinoid spp. (A), *P. conglobatus* (A), inadunate spp. (C), *P. crassioconicus* (S), *P. gordoni* (S), *P. spiniger* (S).

Medium level filter feeders: Bryozoan spp. (A), Dendroid spp. (A).

Low level dpifaunal filter feeders:

1. sessile - *C. sublamelllosa* (C), *E. longispina* (F), *T. polita* (F), *D. aff gillingense* (C), *P. lineata* (C), *P. pleurodon* (C), *T. fifensis* (S), *E. scabricula* (S), *C. urei* (S), *P. undatus* (S), *O. cincta* (S).

2. vagile - *Pectinid spp.* (F), *P. corrugata* (S).

Herbivores and Omnivores: *L. caledonica* (S), *W. mucronatus* (A), *Gastropod spp.* (S).

Carnivores:

1. sessile - *Z. consticta*

2. vagile - *Orthocone nautiloid spp.* (F), *Catastroboeceras spp.* (C)
<table>
<thead>
<tr>
<th>Deposit feeders: <em>N. brevirostris</em> (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of species in biofacies</td>
</tr>
<tr>
<td>Average number of species per level</td>
</tr>
</tbody>
</table>
TABLE 20

Faunal Composition of Biofacies 3
Lettering as in table 18

<table>
<thead>
<tr>
<th>High Level Filter Feeders</th>
<th>Medium level filter feeders</th>
<th>Low level epifaunal filter feeders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crinoid spp. (A), P. congobatus (A), Inadunate spp (F), P. gordoni(S), P. spiniger (S).</td>
<td>Bryozoan spp (A)</td>
<td>E. longispina (F), T. polita (F), S. carbonarius (F)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. aff gillingense (C), C. urei (C), P. lineata (C), P. pleurodon (C).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pectenid spp. (F), P. corrugata (S)</td>
</tr>
<tr>
<td>Herbivores and Omnivores</td>
<td>Carnivores:</td>
<td>Z. constricta (A)</td>
</tr>
<tr>
<td>W. mucronatus (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbivores and Omnivores</td>
<td>Carnivores:</td>
<td>Orthocone nautiloid spp. (C)</td>
</tr>
<tr>
<td>W. mucronatus (C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deposit feeders; 'Halo' burrows (A)</td>
<td>Total number of species in biofacies</td>
<td>49</td>
</tr>
<tr>
<td>Average number of species per level</td>
<td>15.1</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 21
Faunal composition of Biofacies 4
Lettering as in table 18

High level filter feeders - Crinoid spp. (A*), P. conglobatus (A*),
Inadunate spp. (S), P. spiniger (S).

Medium level filter feeders : Bryozoan spp. (A*)

Low level epifaunal filter feeders :
(1) sessile - T. polita (A), E. longispina (F), C. urei (F), P. lineata
     (F), P. pleurodon (F), R. michelini (S), D. aff. gillingense (S).

(2) vagile - Pectenid spp. (F)

Herbivores and Omnivores - W. mucronatus (F)

Carnivores :
(1) sessile - Z. constricta (C)
(2) vagile - Orthocone nautiloid spp. (C)

Total number of species in biofacies = 145
Average number of species per level = 11.2
TABLE 22

Faunal composition of Biofacies 5
Lettering as in table 18

High Level filter feeders: Crinoid spp. (A*), P. congobatus (A*), P. spiniger (F*), Inadunate spp. (S*).

Medium level filter feeders - Bryozoan spp (A*)

Low level epifaunal filter feeders:
(1) sessile - T. polita (A), C. urei (A), P. pleurodon (A), P. lineata (F), E. longispina (C), R. michelini (C), Bascabricula (C), D. aff gillingense (C), T. fifensis (S), R. celticus (S).

(2) vagile - Orthocone nautiloids spp. (F)

Deposit Feeders: 'Halo' burrow (S)

Total number of species in biofacies = 45
Average number of species per level = 18.7
TABLE 23
Faunal composition of Biofacies 6
Lettering as in table 18

High level filter feeders: Crinoid spp. (A*), P. spiniger (S*),
U. bockschii (S)

Medium level filter feeders: Bryozoan spp. (F*)

Low level epifaunal filter feeders:
(1) sessile - E. longispina (A), T. polita (A), C. urei (C),
    P. pleurodon (C), R. michelini (S), E. scabricula (S), D.
    aff gillingense (S).

(2) vagile - Pectenid spp (C)

Herbivores and omnivores - W. mucronatus (F), Gastropod spp (S)

Carnivores:
(1) sessile - Z. constricta (C)
(2) vagile - Orthocone nautiloid spp (S), Catastrobooceras spp (S)

Deposit feeders - Zoophycos spp (S), P. attenuata (S)

Total number of species in biofacies = 45
Average number of species per level = 10.8
TABLE 24
Faunal composition of Biofacies 7
Lettering as in table 18

<table>
<thead>
<tr>
<th>High level filter feeders</th>
<th>Crinoid spp (A*), U. bockschii (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium level filter feeders</td>
<td>Bryozoan spp (F*)</td>
</tr>
<tr>
<td>Low level epifaunal filter feeders:</td>
<td></td>
</tr>
<tr>
<td>(1) sessile</td>
<td>E. longispina (A), T. polita (A), C. urei (A), P. pleurodon (A), R. michelini (S), T. youngi (S)</td>
</tr>
<tr>
<td>(2) vagile</td>
<td>E. neilsoni (A), Pectenid spp (C), P. corrugata (S)</td>
</tr>
<tr>
<td>Low level infaunal filter feeders</td>
<td>L. mytiloides (S)</td>
</tr>
<tr>
<td>Herbivores and omnivores</td>
<td>W. mucronatus (A), Porugifera (S), Gastropod spp (S)</td>
</tr>
<tr>
<td>Carnivores:</td>
<td></td>
</tr>
<tr>
<td>(1) sessile</td>
<td>Z. constricta (S), M. cyclostomus (S), C. crassus (S)</td>
</tr>
<tr>
<td>(2) vagile</td>
<td>Orthocone nautiloids (A), Catastroboconeras spp (C), Cephalopod spp (S), Dithryocaris sp (S*)</td>
</tr>
<tr>
<td>Deposit feeders</td>
<td>P. attenuata (C), Zoophycos sp (S)</td>
</tr>
</tbody>
</table>

Total number of species in biofacies = 46
Average number of species per level = 15.8
<table>
<thead>
<tr>
<th>Level</th>
<th>Taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High level filter feeders</strong></td>
<td>Crinoid spp (A*), <em>P. conglobatus</em> (A*), <em>U. bockochii</em> (A), <em>P. gordonii</em> (S*)</td>
</tr>
<tr>
<td><strong>Medium level filter feeders</strong></td>
<td>Bryozoan spp (F*)</td>
</tr>
<tr>
<td><strong>Low level epifaunal filter feeders</strong></td>
<td><em>(1) sessile - <em>E. longispina</em> (A), <em>T. Polita</em> (A), <em>C. urei</em> (A), <em>T. fifensis</em> (S), <em>P. pleurodon</em> (S), <em>T. youngi</em> (S). (2) vagile - <em>E. neilsoni</em> (S)</em></td>
</tr>
<tr>
<td><strong>Herbivores and Omnivores</strong></td>
<td><em>W. mucronatus</em> (A), Gastropod spp (S)</td>
</tr>
<tr>
<td><strong>Carnivores</strong></td>
<td><em>(1) sessile - <em>Z. constricta</em> (A), <em>C. crassus</em> (S). (2) vagile - Orthocone nautiloid spp (A), <em>Catastroboceras</em> spp (C), Cephalopod spp (S), <em>C. rugosum</em> (S).</em></td>
</tr>
<tr>
<td><strong>Deposit feeders</strong></td>
<td>'Halo' borrow (S), <em>P. attenuata</em> (S)</td>
</tr>
</tbody>
</table>

**Total number of species in biofacies** = 35
**Average number of species per level** = 15.4
<table>
<thead>
<tr>
<th>stipes/cm</th>
<th>Frequency</th>
</tr>
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</tr>
<tr>
<td>6</td>
<td>4</td>
</tr>
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<td>7</td>
<td>10</td>
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<tr>
<td>8</td>
<td>8</td>
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**TABLE 32**

*Polidevicia attenuata* Azimuthal distribution of shell posterior directions. Catcraig column.

<table>
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<tr>
<th>Class Median</th>
<th>Shells at high angle to bedding</th>
<th>Shells in bedding</th>
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<td>-</td>
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<tr>
<td>240</td>
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<td>280</td>
<td>-</td>
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</tr>
<tr>
<td>300</td>
<td>-</td>
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</tr>
<tr>
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<td>-</td>
<td>-</td>
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<tr>
<td>340</td>
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</table>
FIGURE 1

Flow chart illustrating the development of the project
FIGURE 2

Geology of the Catcraig, Skateraw and Dunbar Works area
FIGURE 3

Location map for the Skateraw collection site
FIGURE 4

Location map for the Caterraig collection site
FIGURE 5

Location map for the Dunbar Works collection site
FIGURE 6

The Catcraig, Skateraw and Dunbar Works successions and their correlation
FIGURE 7

Stratum contours on the top of the Skateraw Middle Limestone
STRATUM CONTOURS ON TOP OF SKATERAW MIDDLE LIMESTONE

Contour Interval = 10 Metres
Zero = O.D.
FIGURE 8

Crinoid orientation distributions in the Skateraw Middle Limestone

(a) bed k  Skateraw  (739745)
(b) bed o  Skateraw  (739745)
(c) bed o  Skateraw  (747745)
(d) bed o  Skateraw  (747745)
(e) bed o  Catcraig on bedding plane
(f) bed o  Catcraig under Chaetetes colony

Numbered bars indicate frequency scales
FIGURE 9

Isopach map of mudstone
ISOPACH MAP

MUDSTONE

BOREHOLES
• Complete Section
• Partial Section

CONTOUR INTERVAL = 1 metre

SCALE
0 1000
Metres

COLLECTION SITES = *
FIGURE 10

Isopach map of Skateraw Upper Limestone
FIGURE 11
Isopach map of mudstone and Skateraw Upper Limestone combined
MUDSTONE AND SKATERAW UPPER LIMESTONE
COMBINED ISOPACH MAP

BOREHOLES
• = Complete Section
* = Partial Section

CONTOUR INTERVAL = 1 metre

SCALE
0 1000
Metres

COLLECTION SITES = *
FIGURE 12

Skateraw Upper Limestone - lower ironstone leaf - Skateraw
FIGURE 13

A. Skateraw Upper Limestone - upper leaf - Skateraw
B. Basal shale - 35-50 mm above base - Catcraig
C. Mudstone - 290-320 mm below top - Catcraig
Figure 14

A. Mudstone - 460-490 mm below top - Dunbar Works
B. Mudstone - 2980-3000 mm below top - Dunbar Works
C. Skateraw Upper Limestone - crinoidal limestone - Dunbar Works
FIGURE 15
Diagramatic interpretation of the facies relationships in the mudstone and Skateraw Upper Limestone

Vertical scale 1 cm = 45 cm

The two sections are 1 to 1½ mi apart
A. and B. *Emarginifera longispina*

Ventral valves exhibiting grooved attachment scars
Eomarginifera longispina
Bivariate plot of hinge width against length of
median costa in the ventral valve
Ecograminifera longispina  Hypothetical growth fields

A - A  Adult field
B - T  Adolescent trail forming field
E - E  Juvenile etheridgiform field
D - D  Field of diaphragm positions
FIGURE 19

Epomarginifera longispina
Bivariate plot of dorsal valve width against height
Classification of the C-D interradius in Zeacrinites konincki

**Primitve Type** - Anal-X and Radial in contact with basal circlet.
**Primitive-A Type** - Anal-X in contact with basal circlet. Radial not in contact with basal circlet.
**Advanced Type** - Radial in contact with basal circlet. Anal-X not in contact with basal circlet.
**Advanced-A Type** - Neither Radial nor Anal-X in contact with basal circlet.

Radial = RA  
Anal-X = X
FIGURE 21

Zeacrinites konincki
Cup type frequencies at Dunbar (present study)
and at Invertiel No. 1 Bed, Roscobie and Seafield (Wright 1926)
<table>
<thead>
<tr>
<th></th>
<th>Primitive</th>
<th>Prim.-A</th>
<th>Advanced</th>
<th>Adv.-A</th>
<th>Total</th>
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**FIGURE 22**

*Zeacrinites konincki*  
Example of situs inversus
Zeacrinites konincki  Diagramatic illustration showing the variates measured
FIGURE 24

Zeacrinites konincki Variate frequency distributions
VARIATE FREQUENCY HISTOGRAMS

- **Cup Width (mm)**
  - Primitive Cups
  - Primitive-A Cups
  - Advanced Cups
  - Advanced-A Cups

- **Facet Width (mm)**
  - Primitive Cups
  - Primitive-A Cups
  - Advanced Cups
  - Advanced-A Cups

- **Cup Height (mm)**
  - Primitive Cups
  - Primitive-A Cups
  - Advanced Cups
  - Advanced-A Cups
FIGURE 25
Zeacrinites konincki Variate scatter diagrams
SCATTER DIAGRAMS

- Primitive Cups
- Primitive A Cups
- Advanced Cups
- Advanced A Cups
Zea crinites konincki  
Reconstructed dead 
population size distribution
FIGURE 27
Fossil Population Simulation
Dead Populations
Recruitment variable

Mortality U-Shaped
Growth Linear
Coefficient of Variation 2
No Seasonality Effects

Terms are as defined in Craig and Oertel (1966)
FOSSIL POPULATION SIMULATION.
DEAD POPULATION - SIZE FREQUENCY.

MORTALITY - U SHAPED.
GROWTH - LINEAR.
COEFFICIENT OF VARIATION - 2.
NO SEASONALITY EFFECTS.
RECRUITMENT - VARIABLE.
FIGURE 28
Fossil Population simulation
Live populations
Recruitment variable

Mortality U-Shaped
Growth Linear
Coefficient of Variation 2
No Seasonality Effects

Terms are as defined in Craig and Oertel (1966)
FOSSIL POPULATION SIMULATION.
LIVING POPULATION in SUMMER-SIZE FREQUENCY.

MORTALITY- U SHAPED.
GROWTH- LINEAR.
COEFFICIENT OF VARIATION- 2.
NO SEASONALITY EFFECTS.

RECRUITMENT- VARIABLE.
Fossil population simulation
Dead populations
Seasonality variable

No seasonality
Winter Growth Stoppage
Reproductive Growth Stoppage
Winter Mortality doubled
Reproductive Mortality doubled

Terms are as defined in Craig and Oertel (1966)
Fossil Population Simulation.
Dead Population - Size Frequency.

Mortality - U Shaped.
Growth - Linear.
Coefficient of Variation - 2.
Seasonality Effects Variable.

Recruitment - Single Burst.
FIGURE 30

Fossil Population Simulation
Dead populations
Seasonality variable
Seasonality controls as in figure 29

Mortality U-Shaped
Growth High to Low
Coefficient of Variation 2
Recruitment Single Burst

Terms are as defined in Craig and Oertel (1966)
FOSSIL POPULATION SIMULATION.
DEAD POPULATION-SIZE FREQUENCY.

GROWTH-HIGH TO LOW.
MORTALITY-U SHAPED.
COEFFICIENT OF VARIATION-2.
RECRUITMENT SINGLE BURST.
SEASONALITY EFFECTS VARIABLE.
FIGURE 31

Fossil Population Simulation
Dead populations
Seasonality variable
Seasonality controls as in figure 29

Mortality Modified U-Shape
Growth High to Low
Coefficient of Variation 2
Recruitment Single Burst

Terms are as defined in Craig and Oertal (1966)
FOSSIL POPULATION SIMULATION.
DEAD POPULATION - SIZE FREQUENCY.
MORTALITY - MODIFIED U SHAPE.
GROWTH - LINEAR.
RECRUITMENT - SINGLE BURST.
COEFFICIENT OF VARIATION - 2.
SEASONALITY - VARIABLE.
FIGURE 32

Zeacrinites konincki  Cyp type frequencies on internal and external surfaces
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<td>D</td>
<td>Levels 75 - 84 cm</td>
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<td>F</td>
<td>Levels 155 - 164 cm</td>
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</table>

Numbered bars indicate frequency scales
FIGURE 34

Cinoid columnal orientations (modules 180°)
Dunbar Works column

A  Levels  175 - 184 cm
B  Levels  195 - 204 cm
C  Levels  298 - 307 cm
D  Levels  318 - 327 cm
E  Levels  338 - 347 cm
F  Levels  358 - 372 cm

Numbered bars indicate frequency scales.
FIGURE 35

Crinoid columnal orientations (modulus 180°)
Skateraw and Catcraig columns

A  Skateraw  Levels  1 - 10 cm
B  Skateraw  Levels  11 - 20 cm
C  Skateraw  Levels  51 - 60 cm
D  Catcraig  Levels  1 - 10 cm
E  Catcraig  Levels  31 - 40 cm
F  Catcraig  Levels  51 - 60 cm

Numbered bars indicate frequency scales
A) On a bryozoan fragment, MAW. DW. El8(d1) x 31
b) On a brachiopod fragment, MAW. DW. El8(d1) x 31
FIGURE 37

*Lepidesthes caledonica* Jackson
Ambulacral plates (internal and external surfaces)
MAW. DW. F61(bk), x 10.5
FIGURE 38

Lepidesthes caledonica Jackson
Ambulacral plates (external surfaces), MAW. DW. P61(b5), x 11
FIGURE 39

Lepidesthes caledonica Jackson
Interambulacral plates (internal and external surfaces),
MAW. MW. F 61(bl), x 12.5
FIGURE 40

*Lepidesthes caledonica* Jackson
Aristotle's Lantern (x13)

A) Pyramid (internal and external views) MAW. DW. F61(b10)
B) Teeth MAW. DW. F61(b6)
C) Demipyramid (perradial and adradial faces) MAW. DW. F61(b7)
D) Brace (oral and aboral view) MAW. DW. F61 (b8)
FIGURE 41

Lepidesthes cloughi sp. nov.
Ambulacral plates (external surfaces),
MAW. DW. F61(d2), x 13.5
FIGURE 42

Lepidesthes cloughi sp. nov.
Ambulacral plates (external surfaces),
MAW. DW. F61(d3), x 14
FIGURE 43

Lepidesthes cloughi sp. nov.
Ambulacral plates (internal surfaces),
MAW. DW. F61 (d3), x 14
FIGURE 14

*Lepidesthes cloughi* sp. nov.
Adoral ambulacral plates (internal and external surfaces)
MAW. DW. F61(d6), x 14
**FIGURE 45**

*Lepidesthes cloughi* sp. nov.
Interambulacral plates (external surfaces),
MAW. DW. F61(d1), x 13
FIGURE 46

Lepidesthes cloughi sp. nov.
Interambulacral plates (external surfaces),
MAW. Mf. F61(d1), x 12
FIGURE 47

Lepidesthes cloughi sp. nov.
Interamnlacral plates (internal surfaces),
MAW. DW, F61(d1), x 12
FIGURE 48

Lepidesthes cloughi sp. nov.
Demipyramidce (internal and external views),
MAW. DW. F61(d8), x 10
FIGURE 49

*Lepidesthes cloughi* sp. nov.

A) Brace  MAW. DW. F61(f10), x 12.5
B) Tooth  MAW. DW. F61(d7), x 12.5
C) Epiphysis  MAW. DW. F61(d11), x 12.5
FIGURE 50

?Ptiogruptus dunbarense sp. nov.
Holotype: HAW, DW, A7: Mesh character
A) x 7
B) x 20
FIGURE 51

*Ptiograptus dumberense* sp. nov.

A) Thecae: Holotype, MAW. DW. A7, x 20
b) Ropy stipe and mesh detail, MAW. DW. D4, x 20
A. 

B.
FIGURE 52

?Ptiograptus dunbarenses sp. nov.

A) Large rhabdosome fragment, MAW. DW. E27, x 10
B) Stem, MAW. DW. F50, x 14
C) Spreading mesh, MAW. DW. D62, x 13
D) Spreading mesh, MAW. DW. G73, x 24
FIGURE 53

?Ptiograptus dunbarense

A) Spreading mesh, MAW. DW. 073, x 35
B) Spreading mesh, MAW. DW. Edh, x 2h
FIGURE 54

Dendroid Graptolites

A) ?Ptiograptus dunbarensis, ropy stipe
MAW. DM. 699, x 20
B) Dendroid sp. indet., W/23/27, x 20