THE LOWER CARBONIFEROUS ROCKS
of
THE CARRICK SYNCLINE

by

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CONTENTS

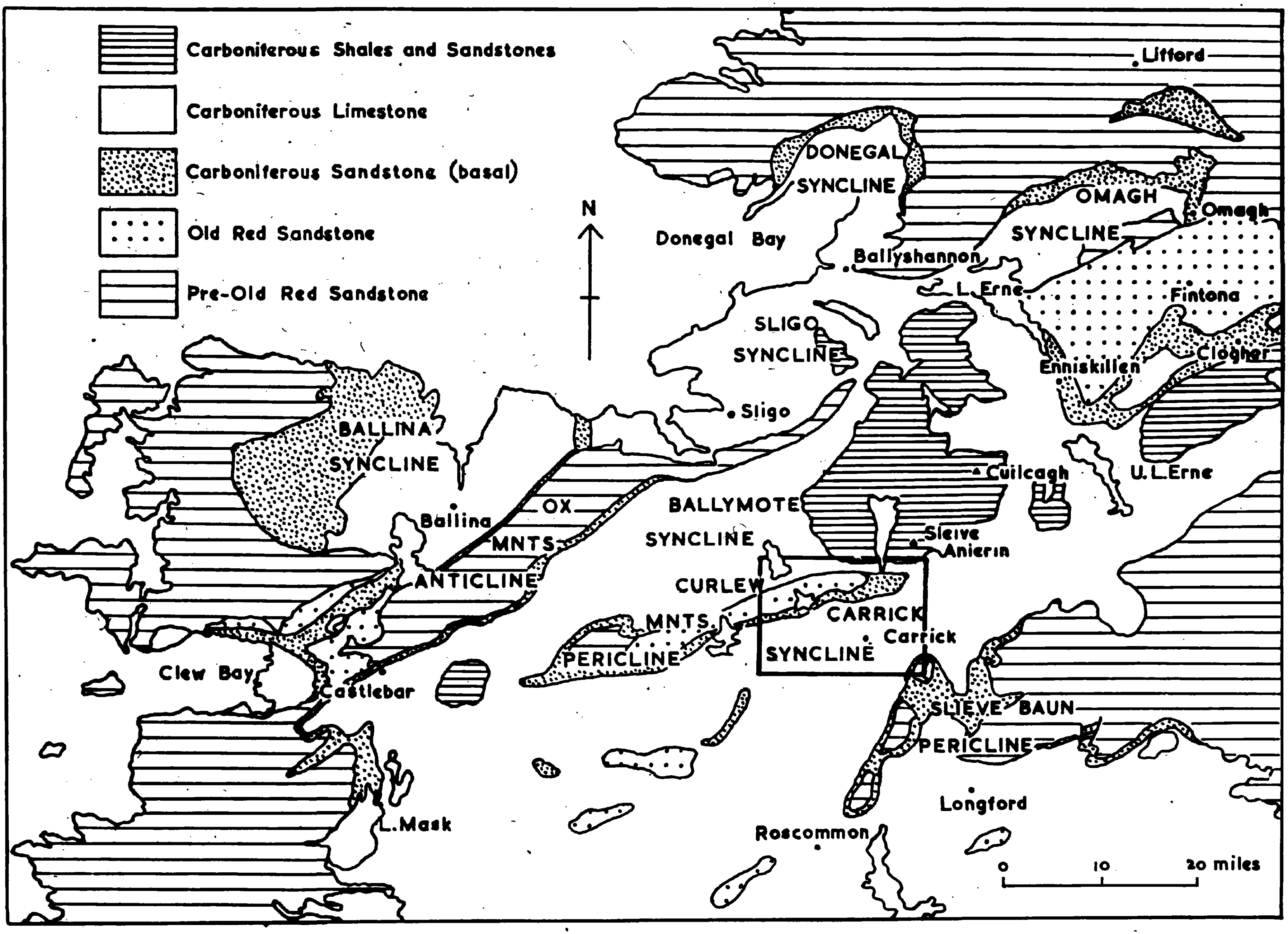

Fig. 1. Geological sketch map of North-West Ireland

I. INTRODUCTION.

South of the metamorphic barrier of the Ox Mountains Lower Carboniferous rocks cease to be confined to isolated synclines such as those of Donegal, Sligo or Ballina but form a gently undulating plain broken only by the mountainous tract of the 'Connaught Coalfield' (a basin of high Avonian and Namurian shales and sandstones) and the conspicuous range of monadnock hills in Old Red Sandstone and Lower Palaeozoic rocks, which, emerging boldly from the flanking limestone lowlands, marks the core of the Curlew Mountains pericline. The Carrick-on-Shannon[1] syncline is a shallow downfold occupying an extensive tract of this flat ground to the immediate south of the Curlew Mountains: it is conveniently regarded as stretching from Lough Gara in the west as far south as the villages of Ballinameen and Clogher, eastwards to Annaduff and Keshcarrigan and north to the base of Slieve Anierin near Drumshanbo (see fig. 1).

The area is one of low relief and the topographical expression of the solid geology has been modified by

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[1] In the title and hereafter referred to as Carrick

ice action such that glacial sands and clays, principally in the form of drumlin swarms, cover large tracts of the ground. Small loughs, frequently impounded by the drift deposits, are a noteworthy surface feature. The wide extent of the drift has rendered difficult a detailed interpretation of structure.

The area is drained by the upper reaches of the River Shannon and its tributaries which, with the exception of the Boyle River, seldom attain significant size. The drainage pattern is completely independent of form in the underlying limestone foundation and the Shannon persistently crosses the structural grain of the country. There can be little doubt therefore that the drainage system is in great measure superimposed although its precise origin remains obscure.

It is probable that a major effect of the mid-Avonian (Nassauian) earth movements was to initiate a rapid and widespread transgression of the Lower Carboniferous sea over the greater part of northern Ireland. Apparently it swept rapidly northwards in early Visean times over a crudely peneplained terrain, drowning the so-called Ulster-Connaught cuvette of Old Red Sandstone sedimentation (a possible continuation of the Caledonian basin of Scotland) and reached the metamorphic foundation beyond the line of the 'Highland Boundary Fault'. The broad caledonoid framework persisted and George (1953, p.65) described the resulting geographical pattern as 'archipelagic' with 'Lower Palaeozoic oldlands' giving rise to a series of (often large) insular landmasses.

The Carrick district became at first the site of a shallow turbulent sea which distributed coarse detritus derived by active erosion of the adjacent upland land areas, but, following wider marine transgressions, these conditions quickly gave way to a relatively quiet warm sea which supported a profuse and varied fauna, mainly of crinoids, brachiopods and corals, and favoured the formation of many kinds of calcareous rocks. In late Avonian times conditions changed and the clear water shelf sea gave way to a muddy sea largely inhibitive to brachiopods and corals; this led to the formation of black shales and impure limestones bearing seams of goniatites and lamellibranchs. These conditions were maintained well into Namurian times.

That the area is composed almost entirely of Lower Carboniferous limestones and sandstones was recognized as early as 1836 when Griffith published a Geological Map of Ireland, his findings being later confirmed by Jukes (1867). Between 1873 and 1878 the Geological Survey of Ireland published the one-inch maps covering the area (Sheets 66,67,77 and 78) with the accompanying explanatory memoirs. The Survey officers adopted the then standard five-fold lithological division of the Irish Lower Carboniferous rocks for the area: Lower Carboniferous Sandstone, Lower Limestone, Middle (or 'Calp') Limestone, Upper Limestone and Yoredale Shales and Sandstones. Tripartite subdivision of the calcareous sequence in the Carrick district is not practicable however, and in consequence both the stratigraphy of the limestones and the structure of the area were misinterpreted.

I express my thanks to Professor T. Neville George for the direction and supervision of my research, for his unfailing interest in its progress, and his invaluable assistance and advice. In comparing and identifying fossil material I gratefully acknowledge assistance from Dr. G.E. Bowes, Dr. R.H. Cummings, Dr. E.D. Currie and Dr. H.M. Muir-Wood, while I desire also to thank my colleagues and friends (particularly Dr. R.H. Cummings) for assistance and stimulating discussion in connection with several aspects of this work. The research was pursued in part during the tenure of a Maintenance Award from D.S.I.R. for which I am much indebted.

II. OUTLINE OF THE SUCCESSION

Although the area has some considerable extent there is little evidence of notable lateral changes in the stratal succession and the following tabular synopsis of the sequence may be regarded as typifying the region as a whole.

Inability to effect precise correlation with adjacent areas and the obvious undesirability of retaining the inappropriate Survey terminology (p.4) has rendered it necessary to introduce a new series of (local) names for the various divisions of the succession. The thicknesses of these divisions should be regarded as only approximate, having been computed, for the most part, from dip and width of outcrop.

	Thickness in feet
AGHAGRANIA SHALES	
P Zone	
Black shales (at times bearing goniatites), calcareous mudstones and decalcified limestones with much finely divided chert. There is one thin group of tough quartzitic sandstones..................	400 (seen)
CAVETOWN LIMESTONE GROUP	
D_1 Subzone	
Variable massive limestones including crinoidal limestones, oolites, dolomites and calcite-mudstones. Many of the beds carry abundant chert nodules and compound corals are profusely abundant at certain levels. Thick reef limestones are locally developed..................................	1,350

	Thickness in feet
CROGHAN LIMESTONE GROUP D_1 Subzone Fine-grained, dark, impure limestones (occasionally containing chert nodules) with calcareous shale partings which decrease in upward succession. Massive crinoidal limestones containing a rich brachiopod-bryozoan fauna form convenient marker beds.........................	350
BALLYMORE BEDS S_2 Zone Richly fossiliferous fine-grained, dark limestones (for the most part crinoidal) with subordinate dark shales. Small patch reefs are developed within this group.........	550
OAKPORT LIMESTONE GROUP S_2 Zone Massive, well-jointed, crinoidal limestones with a thick development of calcite-mudstones and thin impersistent beds of oolitic and algal-rich limestones. Fossils locally abundant.....................	400
KILBRYAN LIMESTONE C_2S_1 Zone Fine-grained dark limestones with shale partings: some even-grained crinoidal beds developed basally which rest sharply on the underlying sandstones. Richly fossiliferous.....	250
ROCKINGHAM SANDSTONE GROUP C_2S_1 Zone Coarse quartz-conglomerates, felspathic sandstones and calcareous sandstones with occasional thin beds of shale and fossiliferous dark limestones. The conglomerates rest unconformably on the Old Red Sandstone.............	400-800

III. ROCKINGHAM SANDSTONE GROUP

The basal Carboniferous sandstones fall into three fairly well-defined divisions:

		Thickness in feet
(iii)	Buff-weathering, blocky, calcareous sandstones and sandy limestones with scattered shelly fossils....................	15 (seen)
(ii)	Mostly white, quartzitic or felspathic sandstones with interbedded thin shales and fossiliferous limestones...........	200-450
(i)	Pale (or red-stained) quartz conglomerates and pebbly grits with interbedded red sandstones, resting unconformably on the Old Red Sandstone..................	150-300

There is a general diminution in grain size in upward succession broadly paralleled by an increase in calcareous content.

(a) Lithology

Rudely stratified conglomerates composed of pebbles of vein quartz, quartzite (occasionally with a conspicuous lineation), jasper and red and green sandstones set in a gritty siliceous or felspathic matrix are typical of the basal beds. The pebbles, which are subangular or rounded, do not generally exceed 2 in. in diameter but cobbles up to a foot in diameter are sporadically distributed. These conglomerates are associated with pebbly grits, pale flaggy sandstones and red-purple sandstones, the last often displaying irregular green deoxidized bands and spheres.

A pebble-conglomerate, petrologically distinct from those already described, crops out locally in the eastern part of the area. The phenoclasts, which are small well-rounded pebbles of red and green sandstones and basic volcanics, are enclosed in a grey-green, gritty matrix and the conglomerate is interbedded with red sandstones. At one locality only it is associated with fine-grained, tough, grey, micaceous sandstones. Patchy distribution of the outcrops within a confined area suggests that this conglomerate is an impersistent development underlying the quartz-conglomerates. In its relation with the overlying sediments it may be comparable with the lowest conglomerate of the Birk Beck Valley sequence in the eastern flanks of the English Lake District (Capewell 1955, pp.36-7) or with that in the Cross Fell area (Harry 1950; Capewell 1956, p.214) where below the Basement Series (Conglomerate Group) there are "sporadic outcrops of conglomerates of a different type".

The lowest part of the Rockingham succession is well displayed between Crossna and Dereenargan: north of Drumcunny Lough conglomerates form bare surfaces and may be seen resting with angular discordance on the Old Red Sandstone.

The overlying felspathic sandstones are characterised by white or pale-grey, massive, fairly well-bedded, poorly jointed sandstones, composed principally of grains of clear quartz and white-weathering felspar. They are not however invariably of this kind: the sandstones may be thinly bedded or flaggy; calcareous or with a high clay and mica content; and texturally they may vary from well-sorted, fine and even-grained sandstones to ill-sorted grits with impersistent strings of pebbles. Varying quantities of iron are present: often the sandstones are only mottled with flecks of iron oxide but certain varieties are more strongly rust-shot and others are highly ferruginous with an ochreous-brown colour. Partial seggregation of the iron content has led in places to the formation of 'box-stones' (when they resemble the Calciferous Sandstone of Scotland) while differential iron staining often enhances many of the sedimentary structures.

Shales and limestones are interbedded with the sandstones. The shales, which may be black, blue, green or purple, seldom exceed a few feet in thickness and generally are sharply demarcated from the sandstones above and below them. Some are micaceous and finely laminated while others are marly and without obvious bedding. The limestones are always dark and impure but vary in texture and composition. They include fossiliferous crinoidal limestones very like the basal beds of the overlying Kilbryan Limestone; brown-weathering impure calcite-mudstones; and finely arenaceous limestones with a highly variable mud fraction. Earthy limestones are sporadically developed and, at one locality, they contain concretionary nodules usually built around the shells of rhynchonellid brachiopods.

In thin section the principal constituents of the sandstones are seen to be quartz, felspars, mica and iron ores in order of abundance (see pl.1.). Many of the quartz grains are strained possessing a marked undulose extinction while a few carry minute opaque inclusions. The felspars are represented mainly by the acid varieties, notably microcline, orthoclase and perthite, with subordinate amounts of plagioclase (usually sodic albite and seldom more calcic than oligoclase), the grains being mostly quite fresh or very slightly altered. Rarely does the quantity of felspar exceed that of quartz but in certain arkosic sandstones it may account for up to 40 per cent of the rock. Mica varies greatly in its proportions but ragged flakes of muscovite are often concentrated in layers accompanied by small amounts of clay material and opaque ores. In certain quartzitic beds flakes of biotite are still preserved. The most common ore minerals are haematite and limonite. Except in the calcareous sandstones interstitial material is at a minimum and the euhedral and subhedral grains of quartz and felspar, being much of a size and tightly packed together, have the appearance of a uniformly granular mosaic.

The recent trenching of the Boyle River, east of Lower Lough Gara, has provided a continuous section for over a mile in the uppermost felspathic sandstones. The succeeding calcareous sandstones and basal limestones crop out on the south bank of the river near Riverside House.

The thin development of more calcareous beds, which mark the top of the sandstone sequence, are buff or yellow, well-bedded, well-jointed, hard, calcareous sandstones and arenaceous limestones, locally fossiliferous with a shelly fauna composed predominently of brachiopods. Where the beds are fossiliferous they are often wholly decalcified or reveal a thick rusty decalcified weathering-skin about a core of fresh rock.

Under the microscope the carbonate content is seen to vary between 15 per cent and 65 per cent and generally to be in the form of clear recrystallised calcite. In places however the calcitic plates have been replaced by an interlocking mosaic of dolomite crystals which display differential iron enrichment. The allogenic constituents are principally subhedral grains of quartz (often strained) and felspar, ragged flakes of muscovite and granules of iron ore but organic debris, including foraminifers and fragments of bryozoans, crinoids and shells, together with scattered recrystallised ooliths, locally reaches significant proportions. Felspar may be sufficiently common to form calcareous arkosic sandstones.

(b) Source of the Detritus

The exact source of the sediment is uncertain. The abundance of the clastic felspars, the high proportion of strained quartz grains and the presence of occasional biotite flakes suggest derivation from a metamorphic-granitic terrain and therefore the Ox Mountains anticline (if it existed as a contemporary insular landmass) and the more distant metamorphic highlands of Donegal and Mayo are a probable provenance. In the Omagh syncline, Simpson (1955, pp.405-6) seeks to derive a thick series of siliceous basal conglomerates mainly from the Dalradian rocks but entertains the possibility of the lowest beds being re-worked Old Red Sandstone. The source of an equally thick group of overlying arkosic sandstones he believes to lie in the Moine granulites. Almost certainly the basal sandstones of the Carrick syncline were derived from much the same kinds of rocks, although the distance which the material has travelled has failed to bring about any significant rounding of the grains.

It is possible that the sediment was derived from uplands of Old Red Sandstone rocks, now exposed principally in the Curlew Mountains inlier and the extensive Fintona tract (see Wilson 1953. pp.306-13 and p.317). In particular this may apply to the basal conglomerates; but the Carboniferous sandstones of the overlying groups, in contrast to the red beds, have a higher proportion of fresh felspar, more mica and less iron; they also have a comparable degree of grain angularity. Thus, for them, it would necessitate some improbable means of preferential mineral selection with the minimum of grain abrasion in an extensive resorting process.

(c) Conditions of Deposition

The rudaceous basement strata represent the initial deposit of the Carboniferous marine cycle. These beds, however, are of deltaic facies, probably the product of rapid fluviatile erosion of a not-too-distant upland landmass and fast deposition (by violently checking the velocity of flow) in a shallow sea which subsequently caused some redistribution.

Evidence of the environment in which the felspathic sandstones accumulated is conflicting. The finer- and even-grained textures point to the erosion of more distant source rocks and more prolonged sorting before deposition but the abundance of the unweathered felspars and the degree of grain angularity demand swift transport and speedy burial.

These sediments are marine: this is indicated by the occurrence of interbedded limestones carrying marine fossils including corals, brachiopods, molluscs and bryozoans. A few quartzitic and felspathic sandstones carry plant remains but these are invariably drifted and, apart from indicating the existence of a nearby landmass, throw little light on sedimentation history. The many kinds of limestones, together with the shales and limy and muddy sandstones, confirm that the environment of sedimentation was changeable and that there was periodic rapid alternation of conditions suitable for the accumulation of thick, current-bedded sandstones on the one hand and shales or limestones on the other.

A quiet, though still shallow-water, environment is indicated by the group of calcareous sandstones which display current-bedding, occasional ripple-marked surfaces and richly fossiliferous pockets.

(d) Faunal Assemblages

Indeterminable plant remains and obscure annelid trails characterise certain beds of felspathic sandstone (in (ii) of p. 7) and pockets of brachiopod shells are not uncommon in the overlying calcareous sandstones. Fossils are otherwise confined to the interbedded limestones but they are rarely well preserved and only in a few cases can they be specifically identified. In addition there are a few molluscs including Conocardium sp. Foraminifera are represented by erlandiids and plectogyrids.

The zonal age of the fossils is inconclusive.

IV. KILBRYAN LIMESTONE

(a) Lithology

The Kilbryan Limestone consists for the most part of alternating limestones and shales, the general facies being that of a zaphrentid phase.

Thinly and irregularly bedded (often slightly nodular), poorly jointed, fine-grained, organic-fragmental or shelly limestones, which are dark in colour due to varying proportions of argillaceous material, are especially characteristic and these are interbedded with subordinate dark shales, which may be calcareous or silty. Less commonly the limestones are more massive, evenly bedded, crinoidal calcarenites: individual beds may exceed 2 ft. in thickness; they have a deeply weathered skin and shale partings are reduced to a minimum. Small geodes and thin veins of calcite are present in certain beds; tabular or irregularly shaped nodules of dark chert are sporadically developed; and a number of fossils, particularly the brachiopods, are beekitized.

Under the microscope the lowest beds are seen to be both arenaceous and dolomitized. The detrital sand grains, which may make up as much as 25 per cent of the rock, have varying shapes and are mostly quartzes (often strained or recrystallised) with subsidiary felspars (microcline and perthite) and rarely grains of epidote (see pl.2). With occasional ooliths they are enclosed in a groundmass of crinoid fragments and dolomite rhombs throughout which there are distributed varying quantities of pyrites, scattered shell fragments, foraminifers and in places considerable numbers of crytostomatous bryozoans, the fenestrules infilled by granules of calcite. Many of the higher limestones have a more mixed character and are composed of fragments of brachiopods, lamellibranchs and crinoids together with trepostomatous Bryozoa, Foraminifera, ostracods and (?)algal tissue set in a groundmass which includes finely divided argillaceous material. The limestones exhibit varying degrees of recrystallisation and in certain of the lower beds it has been selective.

The contact between the Kilbryan Limestone and the underlying blocky calcareous sandstones of the Rockingham Group is exposed at several localities near Boyle and in the Rockingham ground especially at Knockvicar. In all cases the contact is sharp with overlying massive more resistant limestones (generally the first beds are crinoidal calcarenites) weathering to form an overhanging ledge.

(b) Conditions of Deposition

The abrupt change from the arkosic and calcareous sandstones of the Rockingham Sandstone Group to the limestones-with-shales of the Kilbryan Limestone points to a wider transgression of the sea and the establishment of a relatively quiet environment of sedimentation. The fine-grained nature of the terrigenous detritus indicates that the source area was now reduced topographically (such that erosion was less intense) and farther removed from the basin of sedimentation. The large number of unbroken and articulated, delicate, brachiopod shells, the unrolled coral skeletons with encrusting auloporids and bryozoans and the crinoid stalks many inches in length, testify to the existence of tranquil conditions in a shallow sea (probably a few hundred feet deep at the most), the waters of which were well-aereated but yet not disturbed by violent wave- or current-action.

(c) Faunal Assemblage

Fossils occur abundantly throughout the deposit but tend to be most prolific in the shales where they often form nests.

Brachiopods are the most varied of the fossil groups (see pp. 85-92) and include large numbers of pustulose productids, spinous and frilled athyrids, leptaenids, rhipidomellids and schizophoriids -- an association commonly found in zaphrentid phase deposits.

Rugose corals occur in large numbers but are referable to comparatively few genera (see pp. 85-92). Cyathaxoniicids are more or less ubiquitous and while giganteid caniniids may be equally abundant (as for example at Knockvicar) they appear to be more restricted in their distribution. *Cyathoclisia tabernaculum*[2] is common in the basal limestones of the Boyle River section, west of Boyle.

Except for rare specimens of *Syringopora geniculata* tabulate corals are represented only by *Michelinia tenuisepta*. Tall weathered-out michelinid coralla may be freely collected in a small quarry near Cleen cross roads.

There are only a few molluscs and these are principally the gastropods *Bellerophon* and *Murchisonia*. *Pectenid* lamellibranchs and *Conocardium* sp. occur locally.

The remains of fish are not uncommon. Teeth have been found at most localities and at Knockvicar

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[2] Authors of species of brachiopods and corals are quoted in the fossil lists given on pp. 85-92; otherwise they are quoted at the first mention of a species.

large stout fin-spines of Ctenacanthus major Aggassiz[3] showing the characteristic ornament were recovered.

'Fucoids' are found on a number of limestone bedding planes.

Of the micro-fossils the foraminifers are the most recurrent. Erlandiids are common in the lowest limestones and plectogyrids are scattered throughout. Bryozoa are locally abundant in the lowest limestones.

(d) Zonal Position

Although many of the forms found in the Kilbryan Limestone have a long stratigraphic range and are well known from the Tournaisian, the faunal assemblage taken as a whole indicates a Visean age for the deposit. Amplexizaphrentis enniskilleni and Pustula pyxidiformis are typically Visean forms and the abundance of siphonophylloid caniniids suggests a position in the C_2S_1 zone.

The fauna compares closely with that recorded from the C_2 beds of Hook Head by Smyth (1930, p. 542) and of particular interest is the occurrence of large Caninophyllum aff. patulum (see p.117) and Cyathoclisia tabernaculum (p.118) in the faunas from both areas.

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[3] I am indebted to Dr. E.I. White and Mr. H.A.Toombs of the British Museum (Natural History) for Preparing and identifying these remains.

Smyth however, comments on the absence of *Caninia cylindrica* and the *Chonetes papilionacea* group at Hook Head (ibid. pp. 537 & 544) and both are strongly represented in the Kilbryan fauna.

Many of the fossils found in the thin limestones of the Rockingham Sandstone Group are common in the Kilbryan Limestone and thus, tentatively, the former deposit might be grouped with the latter and ascribed a C_2S_1 age.

V. OAKPORT LIMESTONE GROUP

The Group comprises three principal divisions:

		Approximate thickness in feet.
(iii)	Evenly bedded, close-jointed pale and variegated, fine-grained, organic-fragmental limestones, for the most part crinoidal but with thin oolitic horizons. Linoproductids are prolific at certain levels: the *Linoproductus* beds	200
(ii)	Compact, pale and dark calcite-mudstones, many of them algal limestones with oolitic (and rarely pisolitic) lenses and subordinate fine-grained crinoidal beds. At the base: the *Composita* bed	50
(i)	Grey crinoidal limestones (including many even-grained calcarenites), the uppermost beds dark and oolitic; a conspicuous, buff-weathering, compact, basal dolomite rests on the limestones-with-shales of the Kilbryan Limestone	150

Locally (particularly within the Rockingham estate) the limestones below the *Composita* bed may be further subdivided.

(a) Lithology

The lowest beds of the Oakport Group display selective dolomitization. At any one locality the limestones may be uniformly dolomitic for a few feet vertically and a few tens of feet horizontally, but, over a wide outcrop, the development of dolomite is seen to be sporadic, the dolomitized beds alternating and interdigitating with the primary crinoidal limestones. Typically the magnesian rocks are fine-grained, compact, buff-weathering, grey limestones, in thin section seen to consist of uniform euhedral dolomite rhombs (which have completely obliterated the original calcitic constituents) with occasional thin cracks occupied by a more coarsely crystalline mosaic. The selective nature of the dolomitization indicates, almost certainly, post-depositional change and these beds are to be regarded as 'subsequent' dolomites in the sense of George (1954, p.290 footnote). It is perhaps significant that they are developed where the massive limestones of the Oakport Group are in contact with the more impervious limestones-with-shales of the Kilbryan Limestone.

The limestones above the dolomites exhibit considerable variation in colour and texture. For the most part they are bioclastic calcarenites, pale variegated or dark in colour, of an even grain-size, thickly and regularly bedded and well-jointed.

Locally they are coarse-grained and almost wholly crinoidal; thin shale partings separate individual beds; and oolites, dolomites and algal-rich calcite-mudstones are impersistently developed. The limestones are generally massive; individual posts may exceed 5 ft. in thickness and are often delimited at base and top by conspicuous, stylolytic sutures; and a well-defined joint system is in evidence. Chert, in the form of spherical, ovoid or tabular nodules (which may be conspicuously banded) is not uncommon and occasionally the limestones contain small aggregates of crystalline fluorite.

Microscopically many of these calcarenites are seen to be highly recrystallised and only in certain cases can the nature of the primary lithology be reconstructed. Some are organic-fragmental limestones with crinoid and shell fragments, foraminifers, ostracods and sponge spicules still preserved (in various stages of alteration) and set in a matrix of coarsely recrystallised clear calcite, while in others the ghost outlines of the ooliths and crinoid plates are readily distinguished.

The most persistent oolitic horizons of the Oakport Group lie immediately below the Composita bed. Dark oolitic limestones with varying concentrations of organic debris are interleaved with crinoidal beds and dark calcite-mudstones thus constituting a transitional series between the organic-fragmental calcarenite phase and the overlying group in which the calcite-mudstones predominate.

In micro-lithology few of the rocks are seen to be true oolites. The majority are essentially fine-grained, mixed limestones in which the organic fragments (most commonly abraded crinoid particles, shell fragments, ostracods and foraminifers) have acquired a thin oolitic coating apparently devoid of concentric layering. Thus many of the ooliths are highly irregular; their form is largely controlled by their detrital nuclei and, since many of them are elongate or ovoid and without a shelled structure, the 'oolite' which they make up has the appearance, in the field, of a pellet-rock (see pl.3). Like the underlying strata many of these limestones have undergone strong recrystallisation. The ooliths, which are darker than the groundmass due to patchily distributed minute opaque inclusions concentrated in the oolithic film, display evidence of two distinct phases of alteration and the matrix of coarsely crystalline clear calcite has also been recrystallised.

The majority of the oolitic limestones and many of the underlying calcarenites are secondarily silicified in varying degrees by the development of aggregates of chalcedonic silica and widespread euhedral prismatic quartz crystals. In the case of the first rock type the authigenic silica often shows preference for the nuclei of ooliths although the replacement is usually partial and irregular with much calcitic material still visible within the silicified cores.

The junction of the Kilbryan Limestone and the Oakport Group is exposed in a short railway cutting near Boyle. Thin-bedded, dark limestones-with-shales quickly become in upward succession more massive, even-grained and crinoidal and, as the shale partings become reduced, stylolytes develop along the bedding planes and dolomitized beds make their appearance. These limestones in their turn rapidly pass into a group of calcarenites and buff dolomites, which presumably represent the basal dolomite development of the Oakport Group. The cutting is sub-parallel to the strike and, since dips are low, it is difficult to estimate the thickness of the transitional beds but they probably do not exceed 30 ft.

That the subdivisions within these lowest beds are maintained over a wide are is indicated by the exposures at Gortinty Lough, 2 miles south of Drumsna,

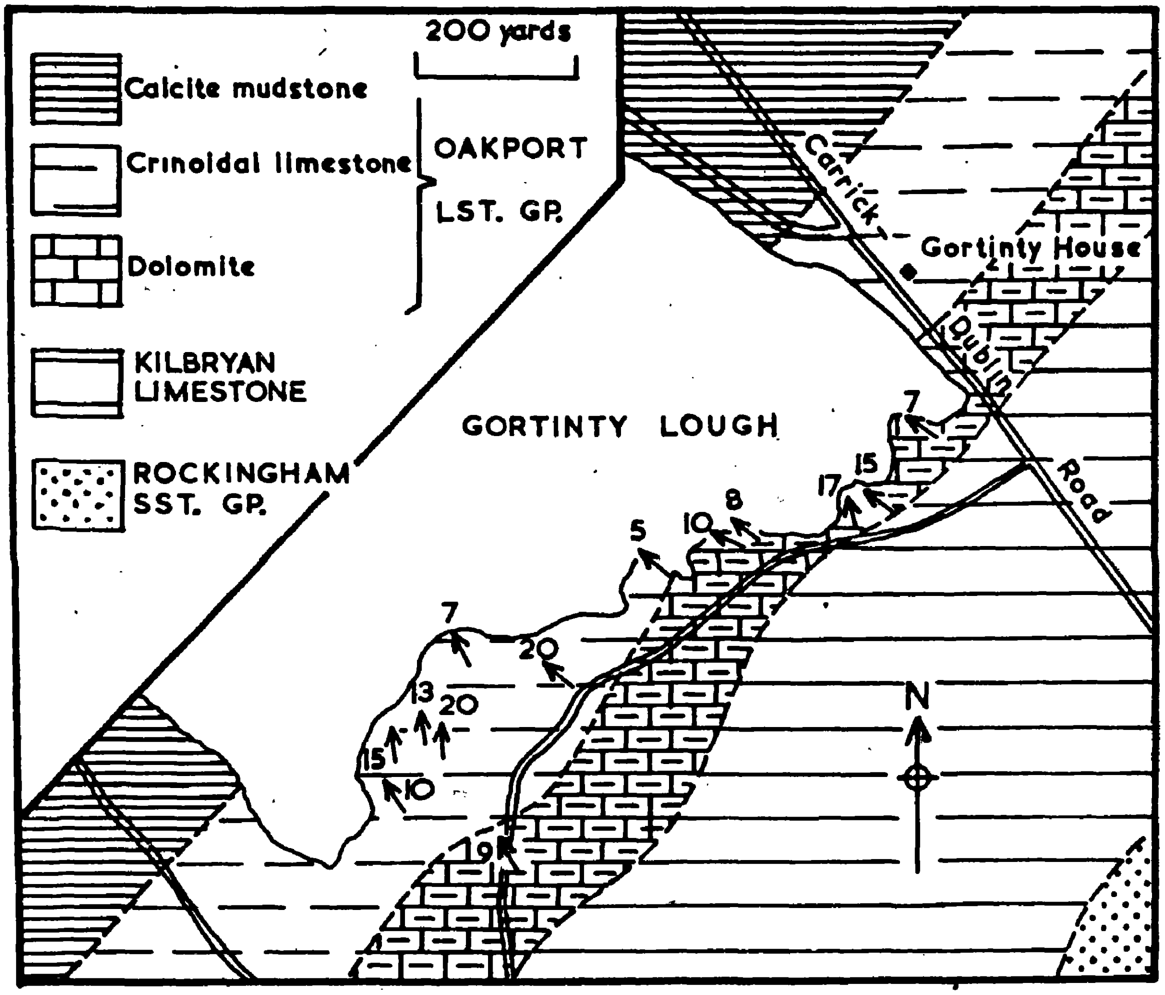

Fig. 2. Map of the solid geology of the Gortinty Lough district

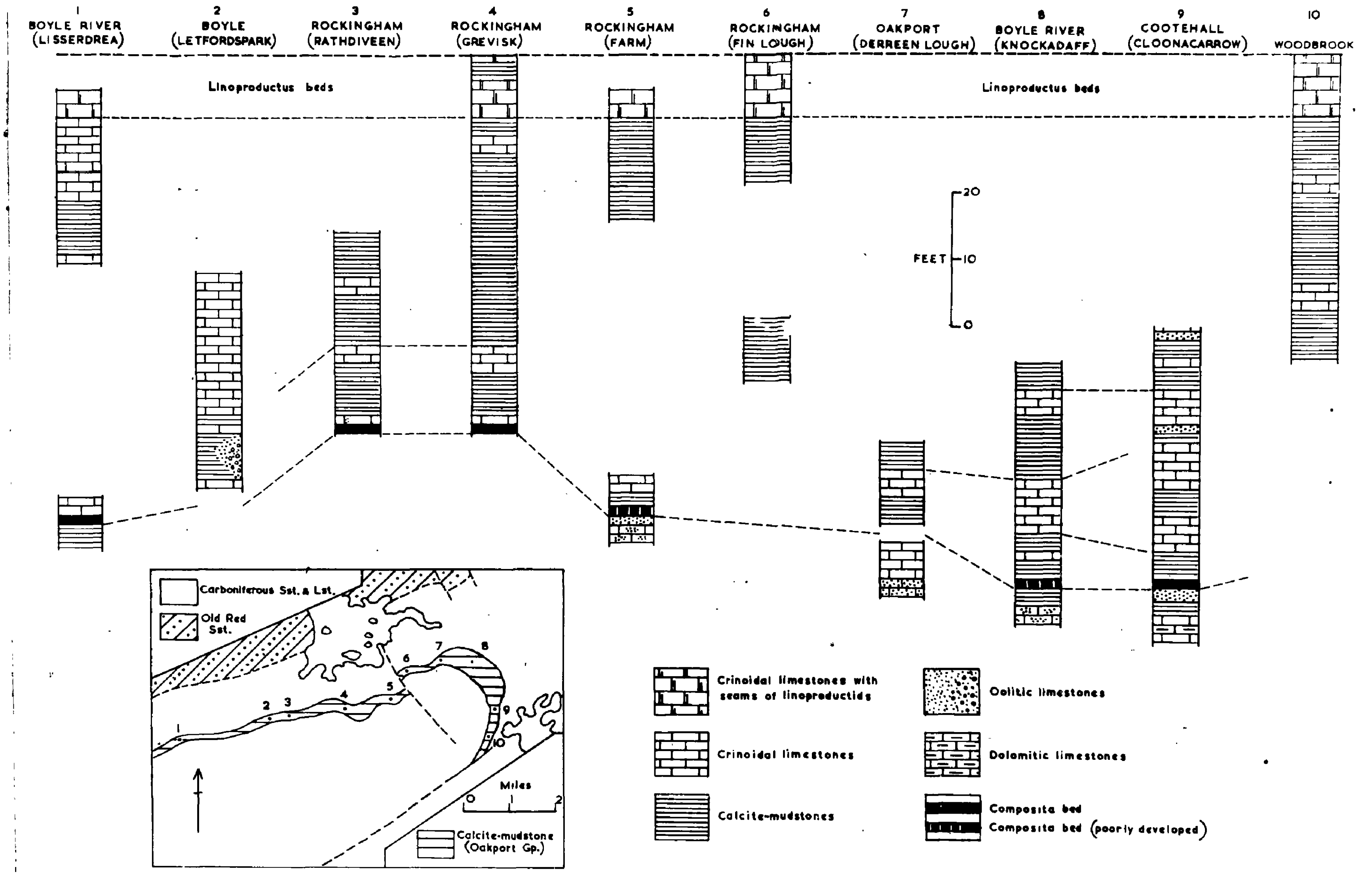

Fig. 3. Comparative sections in the calcite-mudstone beds (Oakport Group) of the Cavetown syncline

where c.60 ft. of compact, differentially iron-stained dolomite is overlain by a mixed series of crinoidal calcarenites differing in no major respect from the equivalent beds in the Rockingham ground (see fig. 2).

For the most part the calcite-mudstones are made up of white-weathering, pale or dark-grey, exceedingly fine-grained, 'porcellanous' limestones; they are well-bedded (wedge-bedded on a small scale), sharply jointed, break with a sub-conchoidal, splintery fracture, commonly contain irregular patches of clear, coarse-grained calcite and rarely display weak banding parallel to the bedding. There are gradations however from calcite-mudstones into fine-grained, massively bedded, crinoidal limestones much like those of the underlying division; they contain occasional oolitic lenses and not infrequently display selective dolomitization. These lithological variations are laterally impersistent and doubtless reflect only minor changes in the environment of sedimentation. Comparative sections (see fig. 3) summarise changes in the calcite-mudstone beds within the Cavetown syncline.

Megascopic examination of a great majority of these calcite-mudstones is quite uninformative, however, and lithologically they appear deceptively simple. But, in thin section, it becomes apparent that many are probably wholly organic limestones, others have a surprisingly high proportion of organic detritus and the majority have undergone complex post-depositional changes. Many of the 'porcellanous' beds are seen to have a high algal content. Small but generically identifiable filamentous colonies, less than a centimetre in diameter usually, can repeatedly be traced grading into strongly mottled calcite-mudstone 'matrix', which in turn may pass into uniformly dense calcite-mud (see pl. 4). George (1954) describing certain calcite-mudstones from Breconshire, said that they include, "..... masses of mud that reveal stages of disintegration from obvious algal forms through vaguely patterned flocks to 'structureless' matrix: in these, although complete proof is lacking, there is the persistent implication that all or nearly all the calcite-mud is ultimately of algal origin. Some of the flocculent mud is mottled or 'clotted' ... and despite some recrystallisation the 'clots' may be primary relics of broken-down algal structure". His remarks are strictly applicable to many of the limestones of this group. Some beds contain mixed crinoid fragments, small shells or bits of shells, bryozoans, algal tissue and calcispheres set in a base of calcite-mudstone (see pl. 5) while in others there are vague areas of finely granular dolomite and/ or scattered well-formed dolomite rhombs. Often clear calcite occupies highly irregular patches entirely surrounded by calcite mud or a coarsely crystalline mozaic may preserve an approximately linear form. George (op. cit. p.306) has suggested these may represent the infillings of shrinkage cracks but in some cases they appear to result from the recrystallisation of crinoid fragments. Rarely there are small cubes of authigenic pyrite.

In essential lithology the Linoproductus beds differ in no major respect from many beds in the calcarenite phase below the calcite-mudstones. They are however more consistently of a kind: fine-grained pale, variegated or dark, even-bedded and very well-jointed limestones. Oolitic beds (some of them conspicuously false-bedded - see pl. 6) are recurrent and there are a few shelly limestones and 'clotted' algal limestones (see pl. 7). Calcite-mudstones are sporadically developed particularly in the lowest 20 ft.

In thin section specimens from the Linoproductus beds show a comparable degree of recrystallisation and secondary silicification particularly with regard to the oolitic horizons. Only in such details as the increased proportions of algal and bryozoan debris, foraminifers and the common occurrence of ostracods and scattered calcispheres do these limestones contrast with similar beds in the lowest part of the Oakport sequence.

The *Linoproductus* beds are spectacularly displayed in the Boyle Limestone Factory quarries and in the Rockingham (Deer Park) and Oakport estates, where often they give rise to griked limestone pavements (see fig. 4). They are well exposed too in small quarries due west of Clogher village, 3 miles south of Jamestown, where one of the most easterly outcrops reveals a sharp contact with the underlying calcite-mudstones. The Clogher exposures, together with those in the lowest group at Gortinty Lough (p.27) are of particular interest in that they show precisely the same divisions exist within the Oakport sequence in this south-east corner of the area as occur in the Oakport-Rockingham ground, more than 10 miles to the north-west.

(b) Conditions of Deposition

The kinds of limestones found in the Oakport Group are in marked contrast to those in the Kilbryan Limestone, for in greater part, they are clastic limestones -- consolidated lime-grits, sands, and muds -- which are the product of a shallow wave-disturbed sea; they may mark a phase of regional uplift.

The crinoidal calcarenites below the Composita bed were probably formed under open-sea conditions. The occasional thin shale partings which occur in the lower beds indicate that fine terrigenous detritus was still being washed into the area, probably produced by the gentle erosion of a hinterland of low relief. The more general light-grey colour of many of the upper limestones suggest that the waters were of more shallow depth and activated by currents which persistently winnowed away any incoming mud. This is supported by the local occurrence of current-bedding in some coarse crinoidal limestones while other beds, in their striking evenness of grain, confirm that there was some sorting prior to deposition.

Broadly the calcite-mudstone beds constitute a Modiola-phase in the sense of Dixon (1911, p.511; 1921, p. 72) but while many of the rocks certainly accumulated in a restricted marine environment similar to that envisaged by Dixon, they are not exclusively the product of 'lagoonal' calcite-pan sedimentation. The intercalated crinoidal limestones and the occurrence of shell fragments, crinoid ossicles and Foraminifera within the calcite-mudstones themselves indicate that the 'lagoon' was subject to periodic incursion from the open sea and under the more or less continuous influence of currents which carried with them the protozoans and organic fragments.

The _Linoproductus_ beds mark a reversion to conditions not greatly different from those which prevailed prior to the deposition of the calcite-mudstone beds. The occurrence of impersistent oolitic horizons and the presence of occasional thin calcite-mudstones however confirm that the sedimentary environment was never far removed from that of lagoon phase sediments.

Thus while the Oakport Group comprises three major lithological units, each with its distinctive kinds of rocks, the fact that the different rock types occur in varying proportions in all three groups suggests that there was no fundamental differences in the conditions of sedimentation controlling their formation, but, more probably, they can simply be related to varying degrees of shallowness within a limited bathymetric range.

(c) Faunal Assemblages

Brachiopods are the dominant fossil group and a full list is given on pp.88-92 . Chonetids are particularly common and include the large *Daviesiella destinezi* found in the crinoidal limestones below the calcite-mudstones. They are closely similar to those described by Simpson (1953) from Tyrone but, in median longitudinal profile, show more marked incurvature of the ventral valve anterior to the geniculation. Papilionaceous chonetids are recurrent fossils of which probably three species are present; the broad (and often strongly convex) *Megachonetes* of the basal Kilbryan Limestone is prolific in the limestones immediately overlying the calcite-mudstones in the Jamestown outcrop; *M.* cf. *multidentata* crowds certain horizons in the lowest division and in the Linoproductus beds; while others from these beds are very like *M. siblyi* (see Sibly 1908, pl.1., figs. 7a-b). *Linoproductus* cf. *cora* mut. S_2 (see pp.114-5) characterises the uppermost 200' of the sequence and occurs rarely at lower levels. Among the spiriferids, the athyrids are dominant. The *Composita* bed is made up of *C.* cf. *gregaria* shells (p.112) with occasional spiriferids; *C. ficoides* forms sporadic impersistent shell-layers in the calcite-mudstones; and the distinctive *C. triloba* - a form included by Davidson in *C. ambigua* - occurs rarely with *Actinoconchus expansus* in the *Linoproductus* beds.

Corals are comparatively rare (see pp. 85-87) except for the tabulate genera Michelinia and Syringopora. M. cf. favosa and S. geniculata occur in the crinoidal beds below the calcite-mudstones and particularly fine, weathered-out, dolomitized specimens are to be had in the numerous quarries on the west bank of the Boyle River between Knockvicar and Cootehall. M. megastoma is not infrequent in the Linoproductus beds. The earliest compound rugose coral is the lonsdaleid Thysanophyllum pseudovermiculare which occurs at the base of the calcite-mudstones in Lisserdrea (North) Quarry and recurs in their uppermost beds of the western shore of Oakport Lough.

Molluscs too are usually uncommon. Gastropods, including capulids, euomphalids and large straparollids, occur in the crinoidal beds of the lowest division in which the lamellibranch Conocardium hibernicum Sowerby is locally abundant. Other small gastropod shells are found in the calcite-mudstones.

In the coarse-grained limestones of the lowest 100 ft. there are often clusters of thick palaeechinid plates and some are recognisable as the disintegrated tests of Maccoya gigas (M'Coy). Archaeocidarid plates are rare.

Among the micro-fossils the Algae characterise the calcite-mudstone beds but are not confined to this horizon. They include colonies of *Ortonella* sp. and less commonly *Garwoodia* sp. while *Koninckopora* sp. also occurs.

Foraminifera are variable in their distribution. The endothyrids are strongly represented and there are ammodiscids, archaediscids, erlandiids and large bradyinids.

Ostracods occur throughout and are sufficiently common in the calcite-mudstones to constitute ostracodal limestones.

Trepostomatous bryozoa occur occasionally.

Many of the fossils, particularly the brachiopods, are silicified.

(d) Zonal Position

The fossils indicate an S_2 age for the Oakport Limestone Group.

Linoproductus 'cora mut. S_2' supported by *Composita ficoides* and (?)*Davidsonina* sp. is confirmatory and the general assemblage, which in addition to the above forms includes lithostrotiontids and carcinophyllids, is impressively similar to that of the Seminula zone in the South West Province of England and Wales.

VI. BALLYMORE BEDS

The Ballymore Beds consist almost entirely of limestones-with-shales and, like the Kilbryan Limestone, they are richly fossiliferous with a zaphrentid phase fauna.

Three subdivisions are recognized:

		Approximate thickness in feet.
(iii)	Dark crinoidal limestones and occasional calcite-mudstones with thin calcareous shale partings. Fasiculate lithostrotiontid colonies are ubiquitous and there are many giganteid caniniids..................	170
(ii)	Nodular or rubbly, thin-bedded, fine-grained dark limestones alternating with dark shales or mudstones. Abundantly fossiliferous......................	130
(i)	Dark crinoidal limestones with calcareous shale partings, interbedded, especially near the base, with massive light-grey crinoidal calcarenites. *Syringopora* occurs commonly: the *Syringopora* beds....................	250

(a) Lithology in the Cavetown syncline

Lithologically the *Syringopora* beds are the most variable. The limestones for the most part are well stratified (in beds up to 2 ft. in thickness), fairly fine-grained, dark grey and crinoidal. Shale partings are reduced to a minimum. Not infrequently however, massive, pale-grey, crinoidal and oolitic limestones, akin in their lithology and fauna to the calcarenites in the lowest beds of the Oakport Group, are interbedded with the lowest shaly limestones and associated calcareous shales. Black nodular chert is present in a few beds.

Many of the limestones are very rich in foraminifers (see pl. 8) with fragments of crinoids, brachiopods and lamellibranchs (some of which are algal filmed), ostracods, cryptostomatous and trepostomatous bryozoans, scattered calcispheres, and rarely small clumps of filamentous Algae, enclosed in a matrix of recrystallised calcite. The groundmass has usually a platy or granular habit, but in a number of limestones it is secondarily altered and replaced, in whole or in part, by euhedral dolomite crystals. The metasomatic changes have clearly been selective, as generally only the groundmass is dolomitized though occasionally dolomite rhombs partially penetrate the organic fragments. Certain of the limestones are argillaceous with crinoid fragments (including many complete ossicles) set in a base of sub-opaque, iron-stained, fine muddy detritus. Small quantities of secondary quartz and granules of ore minerals are usually present.

Thin-bedded, very dark or black, nodular and rubbly limestones, which are fine-grained, often pyritous and associated with thick beds of shale and mudstone distinguish the succeeding division (see pl. 9(a)). Most of the argillaceous beds are calcareous but variable in character: there are all gradations from true shales to poorly laminated or thickly bedded mudstones and siltstones, and it is this group which most clearly exhibits the thin transitional development of weakly fissile muddy limestone often existing between limestone beds and the intercalated shales. Rarely shales predominate and the limestones are reduced to insignificance.

The higher proportion of muddy detritus in these beds is reflected in the micro-lithology of the limestones. Many bryozoan colonies, fragmented shells and ostracods, crinoid debris and a few foraminifers are often embedded in matrix which is markedly more argillaceous than is usual in the underlying and overlying divisions and often contains considerable quantities of fine anhedral dolomite.

The remaining strata of the Ballymore Beds (division (iii) of p.36) resemble the dark crinoidal limestones with thin shale partings of the Syringopora beds. They are however more irregularly bedded, consistently darker and often carry pyrite crystals - lithological characteristics which seemingly complement an increased quantity of detrital mud. Dark, impure calcite-mudstones are locally developed and the sequence includes a few thin coral limestones made up of the skeletons of simple and compound rugose corals. Siphonophylloid caniniids and fasiculate lithostrotiontids (often with the colonies inverted and the interstices between the corallites infilled with a black lime-mud) are the principal components. The coral bed at Knockarush quarry (see pl. 9(b)) displays close resemblance to Oswald's Streedagh Point and Serpent Rock beds (1955, p. 170). Pale and dark nodules of chert appear not infrequently and at certain localities there are veins, from 6 in. to 2 ft. in thickness, of coarsely crystalline calcite which are consistently alined between 50 and 80 degrees south of east.

The similarity of these limestones to the Syringopora beds is more apparent under the microscope. They have the same mixed bioclastic character (although foraminifers are a good deal less abundant) and certain beds show precisely analogous dolomitization effects.

These divisions are most pronounced in the beds exposed in the Plains of Boyle where a small mound of reef limestone (see p. 69) is developed between the richly fossiliferous limestones-with-shales and the overlying lithostrotiontid limestones. These limestones are again particularly well displayed in quarries at Knockarush cross roads, 3 miles south of Boyle where the sequence includes the Knockarush coral bed.

Westwards the divisions become less clearly defined and in the many small quarries around Ballymore there is no noteworthy lithological variation apparent in beds which must equate with the lithostrotiontid limestones and the underlying shaly beds in the Plains of Boyle.

(b) Lateral Changes: the Jamestown Outcrop

In this ground the Ballymore Beds retain their general lithological characteristics and, with certain reservations, the same tripartite grouping is applicable. Nevertheless there are considerable variations in detail brought about by a reduction in the quantity of argillaceous detritus.

The most important change is the increased development of massive crinoidal calcarenites and crinoidal oolites in the Syringopora beds. Quarries near Drumsna railway station reveal thickly and evenly bedded clastic limestones (with seams of linoproductids and papilionaceous chonetids) interbedded with subordinate fine-grained dark limestones with shale partings.

In the overlying division also the limestones are generally lighter coloured and more massive and there are seldom developed the nodular black beds with thick shales of the northern outcrops. A cutting at the western end of the Jamestown canal exposes thickly bedded, dark crinoidal limestones, often dolomitized and with nests of crystalline fluorite, alternating with thin partings of calcareous shale. More argillaceous beds become common in upward sequence.

In the lithostrotiontid beds however the facies is more or less consistent over the entire area. The limestones of the Jamestown outcrop contain a small isolated patch reef (much like that on the Plains of Boyle) but apart from this local development there is no major difference between them and those outcropping in the Cavetown syncline.

At Jamestown the Ballymore Beds occupy a much wider outcrop but since dips are very variable both in amount and direction this is attributed to local flexuring and not to any significant increase in the thickness of the group.

(c) Conditions of Deposition

The lowest limestones (the Syringopora beds) form a transitional series between the non-argillaceous, clastic limestones which underlie them and the highly argillaceous limestones which succeed them and thus they are the product of sedimentation in a gradually changing environment. They too are clastic limestones, often well-washed and sorted, but the dark colour and thin shale partings point to the incoming of an increased quantity of argillaceous detritus or to a diminution in winnowing current action.

In the overlying strata the unsorted character of the limestone beds, the thick intercalations of shales and mudstones, the nature and mode of preservation of the rich benthonic fauna and the associated patch reefs confirm that they formed under relatively quiet conditions by the slow accumulation virtually in situ of organic remains and fine terrigenous muds.

The lithostrotiontid limestones at the top of the Ballymore Beds probably accumulated under conditions directly comparable with those obtaining during the deposition of the underlying beds. The rich coral growth suggests a depth of water of not more than a few hundred feet.

The lateral changes which manifestly take place as the beds are traced southwards suggests that, while in the northern part of the area there was fairly steady deposition of terrigenous muds during the period in which the Ballymore Beds were laid down, in the south accumulation of such detritus was at first discontinuous (whether due to infrequent supply or more active winnowing currents is uncertain) but increased gradually until the sedimentary environment over the entire area became more or less constant when the uppermost beds were being deposited.

(d) Faunal Assemblages

The thin-bedded limestones-with-shales of the Ballymore Beds are considerably more fossiliferous than the massive pale limestones of the Oakport Group. Even within the shaly groups however, beds of apparently the same lithology show striking lateral and vertical variations in the numbers and abundance of different genera and species present. They are especially rich in cyathaxoniicids, caniniids, lithostrotiontids, productids, spinous athyrids, leptaenids, rhipidomellids, schizophoriids and laminose spiriferids. A full list of the brachiopods and corals is given of pp.85-92 .

The majority of the productids are pustulose varieties but there are also species of *Argentiproductus*, *Dictyoclostus*, *Eomarginifera*, *Gigantoproductus*, *Plicatifera* and *Productus*. In the beds exposed near Jamestown there are large specimens of *Daviesiella destinezi*, which agree precisely with Simpson's (1953) description of specimens from Lough Erne.

Laminose spiriferids and spinous athyrids are particularly common in the mid-Ballymore Beds. The spiriferids are represented at most localities by *Tylothyris laminosa* (see p. 116) but *Punctospirifer* sp. and *Spiriferellina* spp. occur locally. In the lithostrotiontid limestones there are thin beds rich in imperfect specimens of *Phricodothyris*.

The lowest Ballymore Beds contain many colonies of *Syringopora*, particularly *S. ramulosa* and *S. reticulata*.

Simple rugose corals with complex central columns are common in the more argillaceous beds and in the uppermost group lithostrotiontids, particularly *L. martini* (see p.120) and *L. scoticum* (see p.121), and giganteid caniniids, often exceeding 3 in. in diameter and 2 ft. in length, are almost ubiquitous. There are also many amplexizaphrentids which exceed 1½ in. in diameter.

Gastropods are the most common molluscs and include *Bellerophon* sp. and *Euomphalus* sp. There are a few lamellibranchs including *Sanguinolites costellatus* M'Coy and nautiloids including *Solenocheilus* sp.

Pockets of trilobite remains include pygidia referred to *Phillipsia* cf. *scabra* (but see pp. 122-3) and to *P.* sp. and of other arthropods the shells of ostracods may be seen in many thin sections of limestones.

Foraminifera abound in the *Syringopora* beds and are less common at higher levels. They include ammodiscids, many archaediscids, erlandiids, nodosariids, tetrataxids, plectogyrids and occasionally very large foraminifers with an agglutinate test wall. The nodosariids appear to be confined to the Ballymore series.

Bryozoa include many trepostomatous and cryptostomatous forms but the particular abundance of the dendroid trepostome *Rhomboporella* (see pl.27a &b) in the shaly limestones of Woodbrook quarry is worthy of note.

Occasional fragments of algal colonies are seen in thin section and there are scattered calcispheres.

'Fucoids' are found on many limestone bedding planes and less commonly in shale layers.

(e) Zonal Position

The Ballymore Beds do not contain any diagnostic zonal brachiopods or corals. Nevertheless the productid fauna suggests an S_2D_1 age which is supported by the presence of common *Lithostrotion affine*, *L. pauciradiale* [=*L. irregulare* auct. non Phillips] and *L. scoticum*.

VII. CROGHAN LIMESTONE GROUP

Broadly the Croghan Limestone Group is a transitional division, in some characteristics resembling the Ballymore Beds and in others the massive, cherty, crinoidal limestones of the Cavetown Group. The succession is:

		Approximate thickness in feet
(iii)	Thin-bedded, fine-grained impure and pyritous limestones which show a progressive decrease in the quantity of fine argillaceous detritus and an increase in the quantity of nodular chert in upward sequence....	170
(ii)	Massive, even-bedded, well-jointed, crinoidal limestones (occasionally oolitic) with a rich and distinctive fauna: the *Pustula* beds....................	50
(i)	Thin-bedded, fine-grained, dark argillaceous limestones with interbedded thin calcareous shales. Richly fossiliferous with a diagnostic faunal assemblage.........................	130

(a) Lithology

Although the limestones below the *Pustula* beds are consistently dark and generally with a thin brown weathering-skin, the fresh rock is often blue and can readily be distinguished from the steel-grey and black limestones of the Ballymore Beds. They frequently alternate with calcareous shales which are mostly confined to thin partings between the limestones but, on occasion, shales crop out in beds a few feet in thickness. Their development however is irregular: the clear-cut rhythmic alternations of the Ballymore Beds are seldom displayed and in this group the limestones themselves carry a greater quantity of mud which is uniformly distributed throughout the matrix.

Thin sections of limestones near the base of the sequence reveal a considerable quantity of muddy detritus forming a sub-opaque base for the included organic fragments (in the main cryptostomatous Bryozoa) and scattered dolomite rhombs. Higher beds are less argillaceous: the groundmass is often recrystallised calcite in which is set a more varied suite of organic remains. In addition to the bryozoans, foraminifers are common and there are crinoid and shell fragments and calcispheres.

Special lithological and faunal characteristics lend an individuality to the *Pustula* beds which makes them distinctive and thus they have proved invaluable as marker beds. They sharply overlie the lower shaly group to which they are in marked contrast.

Generally the beds are grey crinoidal calcarenites which invariably weather to a lighter shade than that exposed in a fresh surface. Individual posts may be defined by thin seams of calcareous shale or, if these are absent, often by poorly developed stylolytic sutures. Yellow or brown limontie is commonly distributed throughout the beds, its occurrence varying from minute flecks to small pockets often replacing or contained within brachiopod shells. Calcite likewise occurs in coarsely crystalline form as a shell infilling. There has been some secondary silicification: tabular or ovoid chert nodules occur sporadically, and at a few localities nodules and lenticles (from a few inches to a few yards in length) weather out from the limestone beds as a result of partial silicification. There are also a few ovoid cavities lined with stumpy crystals of clear quartz.

Under the microscope the Pustula beds are seen to have a more mixed bioclastic character than is evident in hand specimen. They are composed of abraded crinoid, brachiopod and mollusc shell, and bryozoan fragments, many foraminifers, scattered ostracods and algal tissue, enclosed in a matrix of recrystallised calcite which is occasionally clear and platy but more commonly finely granular. Occasionally the beds are oolitic in character: many of the organic fragments are enclosed by a single oolithic film and amongst them are scattered conspicuously shelled ooliths, with small organic-fragmental nuclei (see pl. 10). The secondary silicification is seen as a patchy distribution of cryptocrystalline silica (often as spherulitic chalcedony) which in the nodules and lenticles of silicified limestone is generally confined to the matrix. Well-formed bipyramidal crystals of quartz are also developed which in the oolitic limestones often partially penetrate the ooliths. Rarely there are associated rhombic pseudomorphs of limonite after siderite.

The _Pustula_ beds are abruptly succeeded by an upper group of muddy limestones comparable lithologically to the beds beneath them. The lowest beds are crinoidal limestones and fine-grained argillaceous limestones often packed with silicified colonies of _Lithostrotion pauciradiale_. There are interbedded calcareous shale partings and occasionally, near the base, beds of soft black shales up to a foot or two in thickness. In the upper part of the division exposures are inadequate to determine the detailed lithology but there seems to be a gradual reduction in the mud content in upward succession broadly paralleled by an increase in the number of chert nodules, The highest beds of the sequence are hard, compact, dark-blue, cherty limestones, occasionally fine-grained and crinoidal with patchily distributed pockets of brown limonite - a feature in which they resemble the Pustula beds. They also include dark impure calcite-mudstones.

Many of the limestones of this division are rich in bryozoans and to a less degree in small calcispheres. There are subordinate quantities of comminuted, mixed, organic fragments enclosed in a strongly recrystallised matrix which is noticeably argillaceous and occasionally differentially iron-stained. The matrix includes cubes of pyrites and patchily distributed finely granular dolomite.

The Croghan Limestone Group is most completely known from the Canbo syncline where all three subdivisions are well exposed. The Pustula beds being overlain and underlain by argillaceous limestones, their outcrop is marked by a gentle escarpment pronounced in the vicinity of Killumod, 3 miles south-south-west of Carrick, and again clearly in evidence between Cashel cross roads and Ardglass House, 4 miles west of Carrick, where the marker limestones outcrop freely. The junction between the Pustula beds and the lower shaly group is displayed at Ardglass House, where the sequence is:

	Thickness	
	ft.	in.
Pustula beds --		
Grey crinoidal calcarenites with nodules of chert, patches of brown limonite and small cavities lined with quartz crystals. Richly fossiliferous with a *Pustula*-beds fauna	6	0 (seen)
Beds of division (i) on p.47 --		
5. Fine-grained, dark-blue, hard, compact, crinoidal limestones with orthotetids	1	0
4. Thin-bedded, dark, argillaceous limestones with impersistent lenses rich in coarse crinoidal debris	1	6
3. Fine-grained, dark-blue, hard, compact limestone with crinoids	-	6
2. Calcareous shales with thin ribs of impure limestone	1	8
1. Fine-grained, dark-blue, hard, compact, blocky limestone in thin beds each with a decalcified weathering skin. Fossiliferous with *Michelinia* and productids	3	0 (seen)

Exposures flanking the road from Cashel cross roads to Drumlion are sufficiently numerous to enable fairly accurate reconstruction of the contact between the *Pustula* beds and the overlying division:

	Thickness in feet
Beds of division (iii) on p. 47 --	
5. Fine-grained dark limestones with chert nodules	6
4. Fine-grained, dark, crinoidal limestones with shale partings, nodular muddy limestones and soft black shales. Colonies of *Lithostrotion pauciradiale* at certain levels	30
3. Fine-grained dark tough limestones packed with silicified colonies of *L. pauciradiale*	12
2. Fine-grained, blue limestones occasionally crinoidal with flecks of brown limonite	6

	Thickness in feet
Pustula beds --	
Grey, crinoidal calcarenites with patches of brown limonite and a rich *Pustula*-beds fauna	10 (seen)

Exposures south of the Sheemore--Mong ridge, 4 miles north-east of Carrick, are poor but a rich coral bed (probably in the upper shaly group) crops out in a small quarry below Mong Hill and reappears in exposures at Annaghearly Lough. *Pustula* beds are not seen to outcrop in this ground.

(b) Conditions of Deposition

The essential sedimentary conditions which prevailed during the deposition of the Ballymore Beds were continued in Croghan Limestone times.

The dark limestones contain few corals but a profusion of well-preserved bryozoans and brachiopods (the latter with spines and frills intact) thus, indicating a comparatively still-water environment. Incoming fine terrigenous muds decreased during the phase of deposition.

A sudden temporary change in the environment is indicated by the thick bioclastic calcarenites and oolites of the *Pustula* beds. They probably accumulated in an extremely shallow agitated sea in which there was strong precipitation -- conditions which are in complete contrast to those inferred for the deposition of the shaly beds.

(c) Faunal Assemblages

The Croghan Limestone Group, and in particular the *Pustula* beds, are rich in fossils, brachiopods and bryozoans being the most characteristic groups (see pp.85-92). Those fossils which occur in the calcareous shale beds are often crushed.

In the *Pustula* beds productids are strongly represented and the association includes a large *Buxtonia* sp., *Cancrinella undata* and *Linoproductus* sp. (see pp. 114-5) which occur very rarely at higher horizons. *Echinoconchus eximus* and *Productus* cf. *garwoodi* are apparently confined to the *Pustula* beds but they are only occasionally found. *Pustula pyxidiformis* is the most common brachiopod. The productids are associated with many brachythyrids and leptaenids.

The lower shaly limestones marks the first appearance in the area of *Actinoconchus lamellosus* often accompanied by *Camarotoechia pleurodon* and orthotetids including a distinctive *Schuchertella* sp.

Corals tend to occur in relatively rich beds. At certain levels in the lower limestones silicified colonies of *Lithostrotion pauciradiale* are abundant and this coral is prolific in the limestones immediately overlying the *Pustula* beds. The coral limestones of Annaghearly Lough (see p. 53) contains a varied suite of simple and compound rugose forms including giganteid caniniids, 'advanced' clisiophyllids many showing dibunophyllid stages, *Dibunophyllum* sp. and lithostrotiontids. *Cladochonus crassus* occurs frequently low in the sequence.

Bryozoa abound at all levels. Weathered bedding planes in the lowest limestones are often seen to be crowded with lacy fenestrellinid colonies and many delicate trepostomes, while in the *Pustula* beds cryptostomatous forms are often as abundant as the brachiopods.

Molluscs occur in the *Pustula* beds, the principal representatives being the lamellibranchs *Aviculopecten* sp. other pectenids and *Modiolus* sp.

Trilobite fragments are occasionally found and ostracods are common in the shaly groups.

Foraminifera are prominent among the micro-fossils. They include ammodiscids, common archaediscids, erlandiids, plectogyrids and tetrataxids.

There are common calcispheres in the limestones above the *Pustula* beds.

(d) Zonal Position

The fossil assemblages indicate a D_1 age for the

Croghan Limestone Group.

Among the brachiopods, the large *Buxtonia* sp. is apparently conspecific with that described and figured by Muir-Wood (1928) from the Redesdale Ironstone of Northumberland (S_2D_1) and the species of *Linoproductus* is figured and described by Vaughan (1905) as a variant of L. *cora* common in D_1.

The occurrence of *Dibunophyllum* is conclusive and there is supporting evidence from the clisiophyllid assemblage which is closely similar to that described by Lewis (1930) from the D_1 limestones of the Isle of Man. Significantly too, the majority of the giganteid caniniids (and in fact all those from the Annaghearly coral bed) are referable to *Siphonophyllia* *benburbensis* and similar forms which are common in the D zone in many parts of Britain.

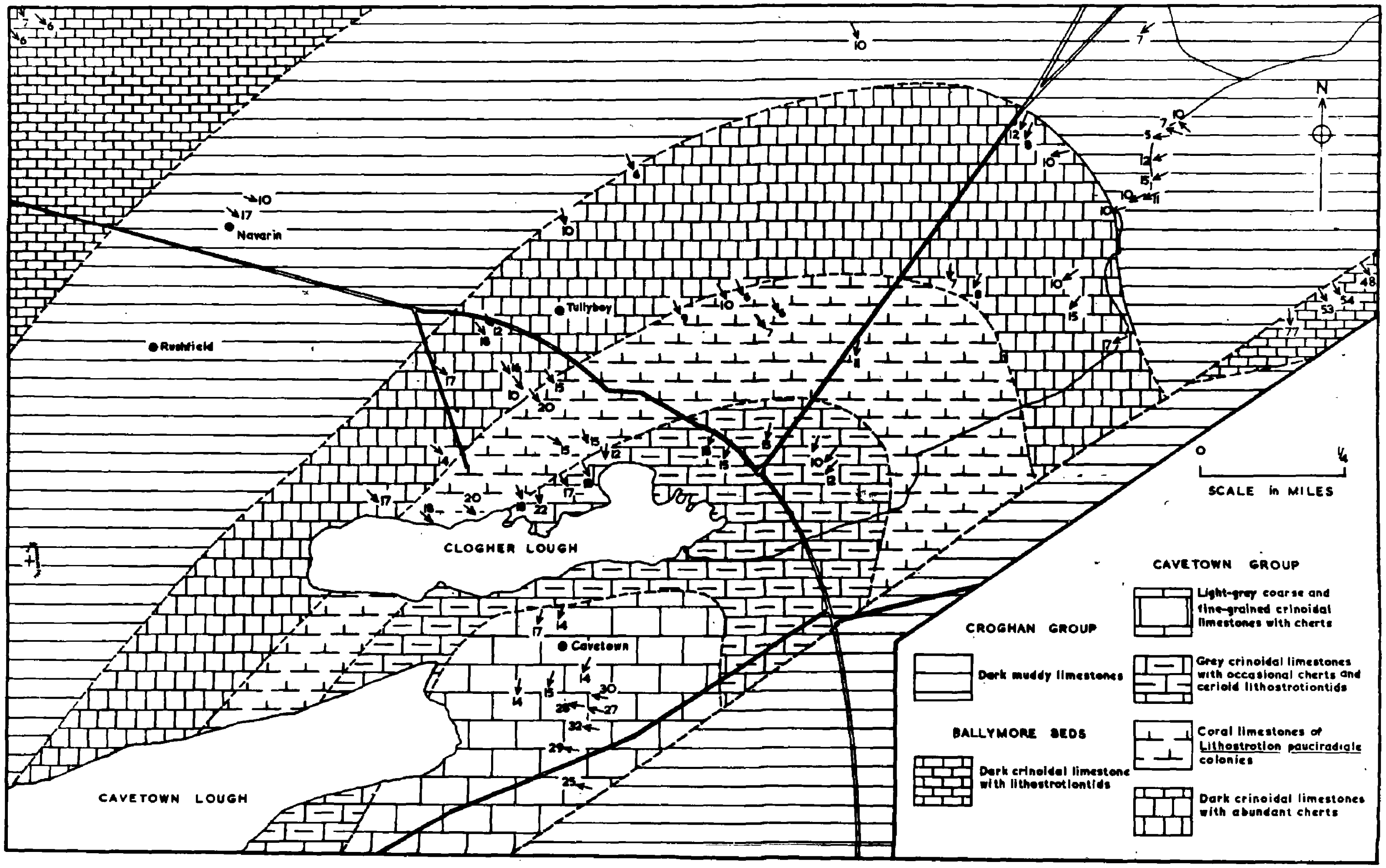

Fig. 5. Map of the solid geology of the Cavetown district

VIII. CAVETOWN LIMESTONE GROUP

(a) Lithology in the Cavetown syncline

At Cavetown there are sufficient exposures to establish four divisions within the Group. These are:

		Thickness in feet
(iv)	Massive, cream and pale-grey, coarse to fine-grained, crinoidal calcarenites with abundant ovoid and tabular nodules of light coloured chert. Contains a prominent bed of <u>Lithostrotion junceum</u>	200 (seen)
(iii)	Thick-bedded, crinoidal limestones, some fine-grained and dark but the majority grey calcarenites with many cerioid lithostrotiontids. Dark chert nodules common at certain levels but for the most part these are wanting	50 (seen)
(ii)	Well-bedded, mostly fine-grained, grey crinoidal calcarenites and fine grained dark limestones with abundant tabular chert nodules and packed with large colonies (in place) of fasiculate lithostrotiontids which are often silicified: the <u>Lithostrotion</u> <u>pauciradiale</u> reef	100
(i)	Fairly dark-grey, crinoidal calcarenites and fine-grained, dark limestones with abundant (mostly tabular) nodules of dark chert; a few thin beds of coarse crinoidal limestone near the base. Seldom conspicuously fossiliferous	250

The surface distribution of the subdivisions is illustrated in fig. 5 .

Broadly the beds of the basal group are the most thinly bedded -- in places they are also unevenly bedded with wisps and thin partings of calcareous shale -- but in the succeeding groups they become more massive, regularly stratified and occasionally delimited at top and base by a narrow zone of stylolytes. Despite the fact that the matrix of the Lithostrotion pauciradiale reef is often fine-grained dark limestone, the beds, as they become increasingly massive, broadly display also an increase in grain size and in the proportionate number of light-coloured beds. The uppermost division is rendered distinctive by its pale-coloured limestones of variable texture.

Local dolomitization often occurs.

Tabular and nodular chert is abundant in the lowest beds and only a little less so in the L. pauciradiale reef. Above the reef it is not so strongly developed: in the immediately succeeding beds it often takes the form of large irregularly shaped 'cobbles' and in the uppermost division many light-coloured tabular nodules occur at certain levels. The cherts are evidently of secondary origin, since, in the coral reef, the silica may replace and completely obliterate the structure of a number of corallites. Joint planes also exert some control on the form of the nodules which often have a bulbous thickening opposite and extending into joint fractures. In a number of nodules the silicification has been incomplete giving rise to the 'incipient' cherts of Dixon 1921, p.137.

In thin section the bioclastic character of these limestones is readily apparent. Invariably crinoid debris makes up the greater part of the rock but there are also shell fragments and spines (mostly of brachiopods), cryptostomatous and trepostomatous bryozoans and foraminifers. Limestones in the uppermost division have a more limited organic content being often almost exclusively crinoid-bryozoan rocks. The organic debris is usually set in a matrix of indeterminable, finely comminuted organic remains or, less commonly, of clear recrystallised calcite.

There is nowhere exposed a contact between what is recognisably Croghan Limestone Group on the one hand and Cavetown Group on the other and indeed, from the several characteristics of each as they approach the 'junction', there may well be complete lithological transition between them. In contrast the L. pauciradiale reef is sharply defined at its base, as may be seen at the foot of the bluff 500 yards north of Clogher Lough, but it is difficult to place a precise upper limit since the coral colonies die out gradually. The base of the youngest division is also arbitrarily defined

(b) Lateral Changes in Lithology: Sheemore and Sheebeg Outcrops

Limestones of the Cavetown Group occupy a broad tract of ground north-east of Carrick. The outcrop is conspicuous, being marked by two prominent outliers -- Sheemore and Sheebeg (see pl. 12(a) -- where the lower part of the following sequence is displayed:

		Approximate thickness in feet
(iv)	Grey crinoidal calcarenites with subordinate coarse-grained limestones, oolitic limestones, calcite-mudstones and fine-grained dark limestones, often locally dolomitized and with much finely divided chert which increases in quantity in upward succession..................	900
	Reef Limestone: there appears to be a more or less constant development of reef limestones at this level. For details see pp. 70-72.	
(iii)	Coarse-grained, grey, crinoidal calcarenites, occasionally with a few chert nodules. At least three thin coral limestones of <u>L. pauciradiale</u> colonies are developed..........................	180 (seen)
(ii)	Grey crinoidal calcarenites with subordinate coarse crinoidal limestones, crinoidal oolites, dolomites and fine-grained dark limestones. Chert nodules irregularly developed. Many beds packed with <u>Lithostrotion pauciradiale</u>.........................	100

	Approximate thickness in feet.
(i) Grey crinoidal calcarenites and fine-grained dark limestones with abundant (mostly tabular) nodules of dark chert. Locally fossiliferous........................	150

Lithologically the lowest group differs in no major respect from that at Cavetown but it is considerably reduced in thickness.

The L. pauciradiale beds comprise a group of limestones highly variable in their lithological characteristics. Crinoidal calcarenites predominate but they show considerable variation in texture and are commonly associated with calcite-mudstones and rarely with false-bedded crinoidal oolites. Changes in colour are no less striking: generally limestones with a coarse texture are cream or pale-grey and those which are fine-grained or oolitic are dark. The white-weathering pale-blue calcite-mudstones however are an obvious exception.

Locally the beds are dolomitized often completely. Massive hard crinoidal limestones are seen to pass laterally into coarse, sugary, iron-stained, often incoherent dolomites, and, although the transformation is effected rapidly, there is obvious interfingering of the primary limestones and the dolomitized beds (usually enhanced by differential weathering) in a narrow intermediate zone a few yards wide. These impersistent developments of dolomite occur at different levels within a restricted vertical range. Patchy dolomitization is evident too on a small scale. A number of the calcite-mudstones have undergone partial alteration and small irregular areas of unaltered calcite-mudstone are surrounded by pale-brown crystalline dolomite such that the resultant limestone looks not unlike a small-scale dolomitized pseudobrexcia (see pl. 11). Fossils often resist these changes: in certain dolomitized limestones crinoid fragments are much in evidence and there are recognisable lithostrotiontids and large solitary corals. Selective metasomatism of this kind is undoubtedly secondary or 'subsequent' although it is uncertain at what precise period and by what agency it took place.

Chert is not so consistently developed as in the equivalent Cavetown outcrops and tends to occur in larger nodules (see pl. 12(b)). Lithostrotiontids too are very much less common appearing most often in thin coral beds.

The variability of the L. pauciradiale beds does not occur in the succeeding group where the beds are consistently crinoidal calcarenites which are usually even-grained and thick-bedded; but it is repeated in the uppermost beds (division (iv) of p. 60) which include limestones of an equally great variety of kinds and in which there is comparable local dolomitization.

Chert is sporadically distributed in the lowest beds of the uppermost division but it gradually increases in upward succession until, in the last massive limestones, finely divided chert makes up as much as 50 per cent of the rock.

Thin shale partings are developed at wide intervals throughout the sequence (possibly accounting for the terraced topography of Sheemore). They increase in number and thickness in the uppermost group and there is a corresponding increase in the number of decalcified or partly decalcified limestones. The cherty rottenstones at the base of the Aghagrania Shales (see pp. 80-1) are the extreme product of these changes.

Under the microscope the bulk of the calcarenites are seen to possess a bioclastic character indistinguishable from that of similar beds at Cavetown; and they show a comparable degree of secondary silicification. Those occuring immediately above the _L. pauciradiale_ beds however are better sorted with the constituent grains, which are much of a size and evenly spaced, set in a groundmass of clear coarsely recrystallised calcite (see pl. 13). A few in the uppermost division recall the calcarenites of the lower Oakport Group in being highly altered by recrystallisation so that it is not always possible accurately to determine the primary lithology.

Similarly in the L. pauciradiale beds, the calcite-mudstones are not greatly different from those of the Oakport Group: they display the same 'mottled' appearance with patches of coarse-grained recrystallised clear calcite and localised concentrations of organic fragments.

Variable oolitic limestones are developed. An example from the L. pauciradiale beds reveals small ooliths associated with large (?)algal clots, both recrystallised and rendered without recognisable internal structure; but oolites from the youngest division are made up of conspicuously shelled ooliths (with the fibrous structure of the layers readily identifiable) together with organic fragments some enclosed in a single thin oolithic skin. Organic detritus invariably forms the nuclei of the ooliths which are enclosed in a clear platy recrystallised calcite.

Roadside exposures between Castlecarra and Kiltoghert Creamery, 2 miles north-east of Carrick (see fig. 6), reveal impure calcite-mudstones with occasional thin shales, ascribed to the Croghan Limestone Group, succeeded by fine-grained limestones (becoming gradually coarser in upward succession)

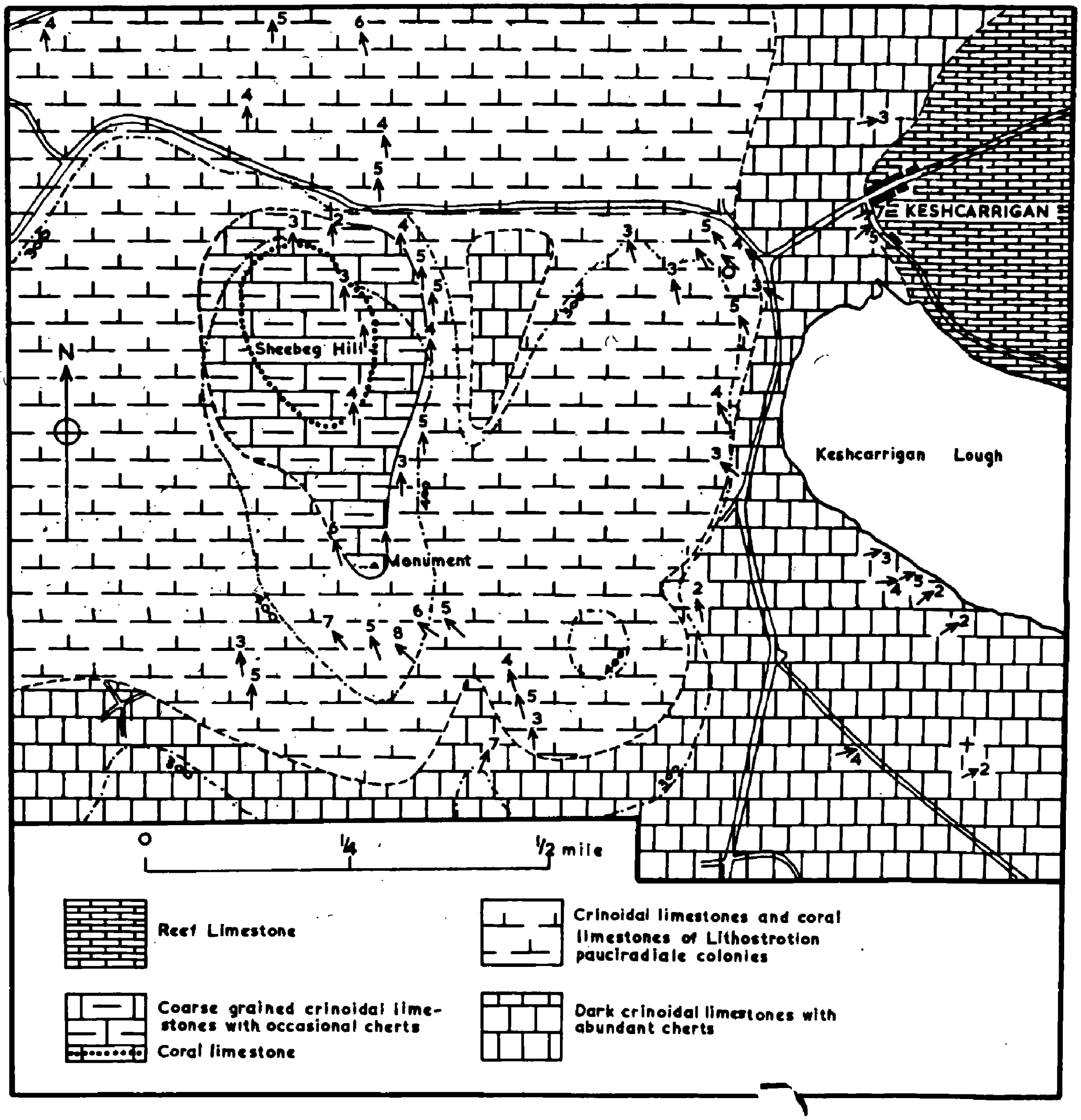

Fig. 7. Map of the solid geology of the Sheebeg district

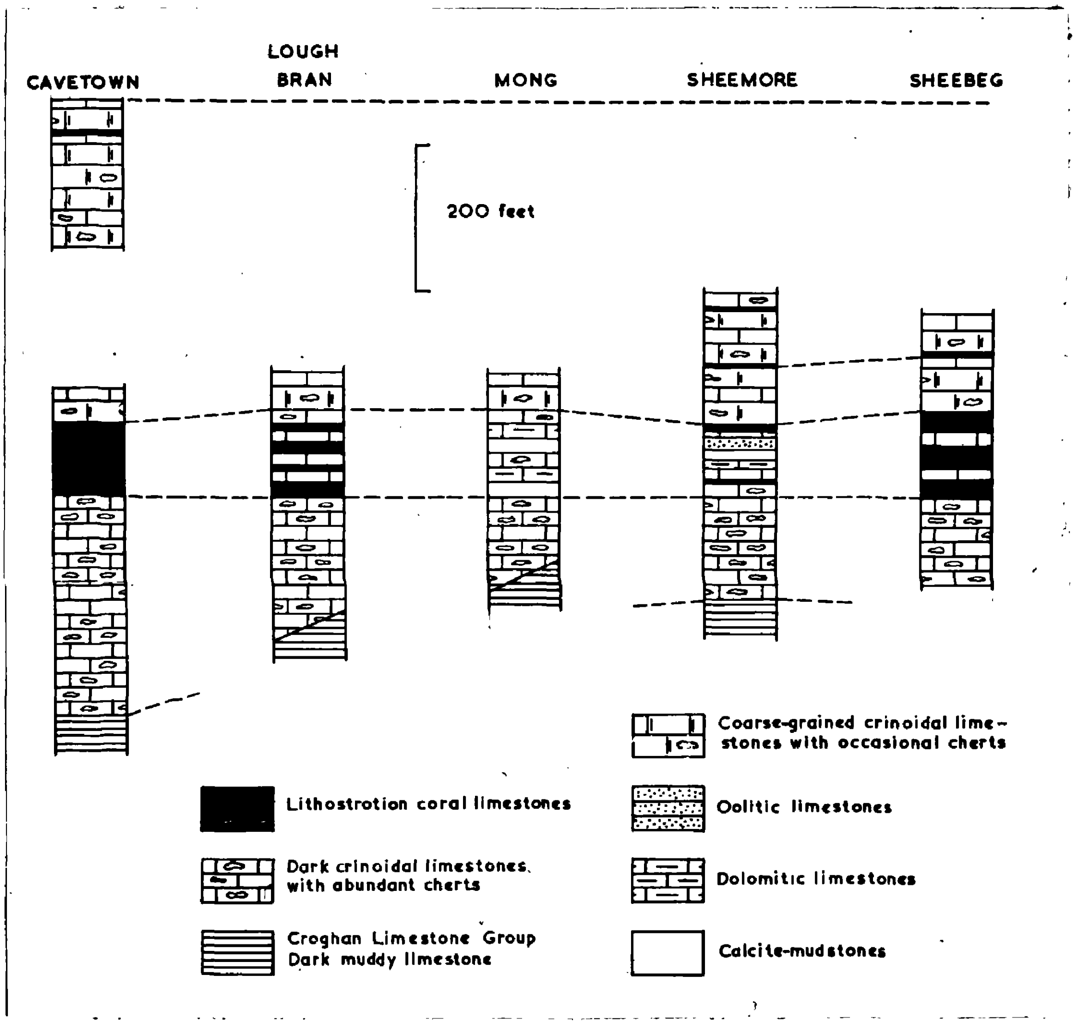

Fig. 8. Comparative sections illustrating lateral variations in the lithology of the lower part of the Cavetown Limestone Group

with abundant nodules of dark chert, referred to the lowest division in the Cavetown Group. The junction with the overlying L. pauciradiale beds is exposed at Lough Bran and on the steep hill slopes of Mong, Sheemore and Sheebeg. The prominent crag of Doonbreen, near Sheemore, displays the varied lithology of the L. pauciradiale beds. A less definite line is drawn between the L. pauciradiale beds and the succeeding group but the junction can be most accurately established on the three outliers (see figs. 6 and 7).

The comparative sections of fig. 8 illustrate the lateral changes in the Cavetown Group.

(c) Conditions of Deposition

Reversion to conditions of sedimentation, like those which existed for the greater part of Oakport Limestone times, is indicated by the general lithology of the Cavetown Limestone Group.

The L. pauciradiale reef, with its tall widely spread, branching coralla, lithified in the position of growth (see pl. 14), suggests that the colonies grew on the bottom of a clear, warm, shallow sea with activated waters but beyond the reach of destructive wave- and current-action. The fact, however, that it passes laterally into the mixed calcareous sequence of the L. pauciradiale beds (division (ii) of p. 60), which have numerous thin coral reef beds, suggests that these conditions were not so specialised as to be greatly different from those in which the 'normal' limestones were accumulating.

Extreme shallowness and strong precipitation is indicated by the recurrent thin oolitic beds and calcite-mudstones interbedded with the clastic calcarenites. Indeed the brecciated pitted surface of a number of bedding planes in the calcite-mudstones is a pointer to sedimentation virtually at water level. On the other hand occasional thin shale partings reveal that small quantities of fine terrigenous mud were still being periodically brought into the area or alternatively that there were temporary lapses in the winnowing action of off-shore currents.

(d) Faunal Assemblages

In contrast to the underlying limestones those of the Cavetown Group are richer in corals than in brachiopods, the lithostrotiontids being particularly characteristic. Colonies of _L._ _pauciradiale_ occur at all levels and form the principal component of the coral reef beds. _L._ _junceum_ makes a rare appearance high in the sequence, together with a large dendroid species of the _affine-phillipsi_ group (see p. 119).

The compound forms are accompanied by large numbers of simple corals which include caniniids, clisiophyllids and cyathaxoniicids. Dibunophyllum sp. occurs rarely.

Most groups of brachiopods are represented but probably the pustulose productids and the gigantoproductids are the most abundant. Many of the gigantoproductids are not specifically identifiable: fine-ribbed latissimoid forms which possess a thin shell and a narrow visceral chamber may well be species of Semiplanus, but the specimens are without trace of cardinal spines and do not reveal internal features. In others the ribbing is distinctly coarser approaching the edelburgensis type.

Clusters of palaeechinid and crinoid plates are found commonly in the L. pauciradiale beds of the Sheemore ground and this division also contains a bed with many specimens of the blastoid Orbitremites derbiensis (G.B. Sowerby).

Of the arthropods, ostracods are the most common representatives being present in most limestones; and locally there are pockets of trilobite remains.

There are often strong concentrations of bryozoan debris including many types of trepostomes and cryptostomes.

Foraminifera are seldom abundant but there are representatives of the ammodiscids, archaediscids, erlandiids, plectogyrids and tetrataxids. In addition there are a few scattered very large specimens having an agglutinate wall structure.

(e) Zonal Position

Dibunophyllum and *Lithostrotion junceum* confirm a D age for the Cavetown Limestone Group, which is supported by *Caninophyllum archiaci* and the abundance of *L. pauciradiale* and the ceroid lithostrotiontids. The Group is overlain by P_1 shales and hence it is highly probable that the greater part belongs to the D_1 subzone.

IX. REEF LIMESTONES

Reef limestones are developed at different levels in the succession. Extensive sheet reefs, not topographically conspicuous, are interbedded with the massive, cherty, crinoidal calcarenites of the Cavetown Limestone Group, and in the upper part of the Ballymore Beds there are two small patch reefs giving rise to low mounds or knolls. These reefs are accumulations dominantly of calcite-mudstone which show little or no recognisable internal structure and contain only occasional pockets of fossils. They are to be distinguished from the L. pauciradiale reef which is a forest of large coral colonies preserved in position of growth.

(a) Lithology

(i) Ballymore Beds.

On the Plains of Boyle, a small hillock of calcite-mudstone intervenes between the Syringopora limestones and the more argillaceous beds above them, (see pl. 15(a)). In present outcrop it measures about 300 yards by 200 yards and is elongated in a north-south direction. Exposures are poor but more than one locality at the northern end of the mound (and not far above the base) reveals bedded reef rock inclined at less than 5 degrees 'inwards' towards the reef centre. The regional tectonic inclination is in the same general direction and of the same order, hence the reef beds at these localities were probably originally disposed horizontally.

In the Jamestown outcrop, near Cloonfad House, a small knoll rises sharply above peat and glacial drift. Compared with the mound of the Plains of Boyle it is probably about twice the size and is elongated in the direction of the regional strike. Exposures are confined to the north-west margin where bedded calcite-mudstones crop out. The bedding planes follow the surface topography and the dips (at 15 to 18 degrees) are steeper than those observed in any adjacent exposures of non-reef limestones. The reef probably lies within the lithostrotiontid limestones at the top of the Ballymore sequence.

These may well be true reef knolls (in the sense of Tiddeman 1890) although it cannot be demonstrated conclusively that they accumulated precisely in the manner originally envisaged by him.

(ii) Cavetown Group.

The term <u>sheet reef</u> has been employed for the bryozoan-rich reef of Benbulben in the Sligo syncline (see discussion of Oswald 1955 and George 1953, p.72): it is described as not having an abrupt knoll form and behaving as an enormous interleaved lenticle in the midst of bedded organic-detrital limestones. While the Carrick reefs are not invariably rich in bryozoa this description is otherwise applicable to them.

The degree of stratification in the sheet reefs is variable: in places the limestone is distinctly bedded with individual beds often exceeding 4 ft. in thickness and maintaining reasonably constant proportions when traced in the directions of dip and strike; but in others it is massive, unbedded (or obscurely bedded) and reveals only sparsely distributed indeterminate planes which are impersistent in extent and display little consistency in direction and inclination. Bedding appears to be most pronounced near a reef base.

The reefs do not give rise to any distinctive topographic features but often outcrop in a series of low scrub-clad mounds which may be discrete or continuous. These mounds are not of sedimentary origin however since, when the limestones are stratified, they are seen to be traversed by the bedding planes.

For the most part the reefs consist of extremely fine-grained calcite-mudstone or 'porcellanous' limestone which in a fresh surface is usually dovegrey (but not infrequently dark-grey) and which weathers with a milky-white skin. Clear crystalline calcite, in the form of irregular patches or a reticulum of thin ramifying veins, is often associated and crinoidal debris is present in varying concentrations.

In places the rock is crowded with Bryozoa forming (as at Benbulben) a bryozoan reef. The lacy colonies are often sheeted and, if the reef is bedded, they lie in approximate parallalism with the bedding planes. Weathered-out dolomitized colonies often impart a honeycomb appearance to the reef rock, especially if their orientation is somewhat irregular.

Under the microscope typical reef limestone is seen to be composed largely of sub-opaque calcite-mud that has undergone strong diagenetic recrystallisation. It usually contains subordinate quantities of organic debris including crinoid remains (often unabraded), fragments of brachiopods and molluscs, ostracod shells, foraminifers and calcispheres. There are veins of coarsely recrystallised platy calcite and occasionally euhedral crystals of secondary quartz and pyrite.

(b) Relation with the enclosing limestones

Exposures are too poor to determine conclusively the relationship between the reef limestones and the bedded clastic limestones which underlie, overlie and flank them.

The base of a reef is seen in a small quarry at Keshcarrigan where a few feet of reef limestone are preserved resting sharply on dark crinoidal limestones with many thin tabular nodules of chert (see pl.15(b)). When traced towards the contact the bedded non-reef limestones become gradually fine-grained and pale-grey in colour while the chert nodules disappear; nevertheless a clearly defined, distinctly irregular, physical break always separates these beds from the calcite-mudstone of the reef proper and the junction appears abrupt if not disconformable. This relationship compares with that at the base of the Hall Hill (Bowland) reef described by Black (1953, pp.347-8). A few feet above the junction there is an isolated exposure in reef breccia.

Recent excavation in Carrickbaun quarry near Drumshanbo has exposed very imperfectly a passage between reef and an overlying development of impure bedded limestones. The true reef rock, of which only a few feet are seen, is unbedded and richly fossiliferous with much coarse crinoidal debris. In upward succession there is an increase in this detritus, which with deepening colour, causes the reef limestone to gradually lose its identity and pass into well-bedded, dark, non-reef limestones. These attain a thickness of about 30 ft. Impure calcite-mudstones predominate but elongate lenses of coarsely fragmental crinoid limestones are developed and contain nests of productid and spiriferid brachiopods. These are succeeded by more thin-bedded, fine-grained, impure and pyritous, platy limestones with thin shale partings which reach a slightly greater thickness. In the beds immediately succeeding the recognizable reef limestone the dip is about 60 degrees but this decreases in the higher non-reef beds to not more than 30 degrees. It may well be therefore that a depositional component of dip is to be recognised but the close proximity of the Curlew Mountains fault to the zone of steepest dips (the quarry lies on the downthrown side and the effective displacement exceeds 2000 ft) may provide a tectonic explanation for the comparatively sudden change.

There is nowhere exposed a lateral passage from reef to non-reef limestone of the kind described by Oswald (1955, p. 178) but at Liscarban, 3 miles east of Drumshanbo, thin beds of reef rock with the characteristic faunal assemblage inosculate with beds of massive crinoidal limestone containing the fossils typical of the Cavetown suite. Transition from calcite-mudstone to crinoidal calcarenite is usually abrupt but, less commonly, there is a gradual change as crinoid detritus increases. The resultant clastic limestones are lithologically indistinguishable from those at considerably lower and higher levels in the Cavetown Group since occasionally they carry chert nodules, are separated by thin shale wisps and are subject to severe secondary dolomitization.

(c) Conditions of Deposition

Accumulation on the muddy bottoms of local swells which arose on the sea bed probably accounts for the small patch reefs of the Ballymore Beds but the thicker and more widespread reefs of the Cavetown Group point to the existence for more lengthy periods of conditions appropriate for reef formation and suggest a more extensive shallowing. George (1953, p. 72) has suggested that the Ox Mountains anticline, actively rising during Avonian sedimentation, may have contributed to the development of the peculiar reef-forming conditions in the Sligo area; and, from the manner in which the reefs are distributed on both flanks of the Curlew Mountains anticline, it might be inferred that this axis exerted a comparable influence.

Within the reef rock there is no recognisable organism (or group of organisma) present in sufficient numbers to have imparted any rigidity to the reef structures. Locally the encrusting bryozoans may have been the frame builders but they are not invariably present -- indeed locally they are seen to be strongly developed in narrow bands (a foot or two in thickness) in the midst of massive, apparently unfossiliferous reef limestone, and doubtless were susceptible to minor changes in environmental conditions. Compared with the 'porcellanous' limestones of the Oakport Group, the reef limestone, in thin section, fails to reveal any strongly developed 'mottling' or 'clotting' (although in some limestones it is incipient) that might hint at algal origin, and there is certainly no recognisable algal tissue. The problem is equally acute in the reefs of the English Midlands, where in certain cases, such as the upper reef limestone in the Manifold Valley (Prentice 1951, pp. 190-1), Algae clearly functioned as frame-builders.but in others as in the Carrick reefs a recognisable organic source is not evident. Direct chemical precipitation from sea water saturated in calcium carbonate has then been generally (though conjecturally) invoked for an explanation.

(d) Faunal Assemblages

Productid brachiopods are the most abundant fossils in the patch reef of the Plains of Boyle but there are also many cryptostomatous bryozoans. Molluscs are represented by pectenids and *Euomphalus* sp.

At Cloonfad House the reef contains the unusual association of many colonies of *Lithostrotion pauciradiale* and camarotoechiids.

The sheet reefs of the Cavetown Group formed an ecological niche especially favourable to bryozoans and brachiopods.

In the bryozoan reefs fenestrellinid cryptostomes are most common but there are also many kinds of delicate trepostomes among which *Ichthyorachis* sp., *Ptylopora* sp. and *Synocladia* sp. are prominent.

The brachiopods tend to occur in relatively rich pockets: they are often undersized and some, notably spiriferids, are deformed. The rhynchonellids *Camarotoechia pleurodon* and *Pugnax pugnus* are perhaps the most common. They are closely followed by the athyrids and by species of *Brachythyris*, *Martinia* (including a strongly plicate form common in the Elbolton knoll of the Cracoe district) and *Spirifer*. Among the productids species of *Plicatifera* are relatively abundant. Giganteid specimens of *Schizophoria resupinata* (often ascribed to *S. gigantea* Demanet, but see Bond 1941, p. 290) may be collected at Carrickbaun quarry. A full list of the brachiopods (and corals) is given on pp. 85-92.

Corals occur rarely and are usually confined to the better stratified lower part of the reefs. They include *Amplexus coralloides* and other solitary rugose forms (some of which are cornute), *Lithostrotion pauciradiale*, and occasional micheliniid and syringoporid tabulates.

Among the molluscs the many and varied species of *Pecten* are worthy of note and there are occasional orthocerate nautiloids.

Of the arthropods, ostracod shells are seen in most thin sections although they are never abundant (compare the calcite-mudstones of the Oakport Group pp. 27-29) and there are also occasional pockets of fragmented trilobite remains.

Scattered plectogyrid foraminifers are present.

Since the standard coral-brachiopod fauna is absent, the zonal age of the assemblage found in the reefs is uncertain.

X. AGHAGRANIA SHALES

At the top of the Cavetown Limestone Group a fundamental change in the environment of sedimentation is reflected in the gradual but distinct transition from the calcareous to the shale facies. The resultant strata -- the Aghagrania Shales -- are quite unlike any development at lower horizons in the Carboniferous succession. Padget's work (1953) on Cuilcagh has shown the inappropriateness of the term 'Yoredale' for these beds, to which George (1953, p.72) and Oswald (1955, p.179) have already drawn attention.

(a) Lithology

The lower reaches of the Aghagrania River, north-east of Drumshanbo, offers the most satisfactory exposures in the uppermost beds of the calcareous sequence and in the overlying goniatite-bearing shales. The section is incomplete and numerous short breaks, together with the presence of many small drag folds (and possibly also minor faults) in the incompetent beds, have prevented accurate determination of thicknesses. The succession reads as follows:

	Approximate thickness in feet
10. Black shales with intercalated nodular calcareous mudstones. Richly fossiliferous with many crushed goniatites including *Goniatites granosus* Portlock and *Sudeticeras* sp., molluscs and brachiopods	15 (plus)
9. Hard, well-jointed, fine-grained limestones (including impure calcite-mudstones) and calcareous shales with many brachiopods	c.45
8. Alternating bedded cherts and thin, pale or purple, decalcified limestones	40
7. Hard, well-jointed, impure calcite-mudstones highly argillaceous limestones and calcareous shales, shale increasing at the expense of limestone in upward succession. Richly fossiliferous with goniatites including (?)*Goniatites falcatus* Roemer, molluscs and brachiopods	c.150
6. Light-coloured, micaceous shales with thin ribs of tough, blocky, fine-grained, green sandstone	15
5. Massive, grey and pale-green sandstones with a brown weathering-crust	6

Aghagrania Bridge

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4. Dark, impure calcite-mudstones and nodular calcareous mudstones with occasional nodules and bands of chert, alternating with dark shales. Basally there are developed thin bands of fine, compact, magnesian limestone (cement-stones), brown, granular dolomites, dolomitized crinoidal limestones and decalcified limestones with scattered, irregularly-shaped, chert nodules, Ironstone nodules occur occasionally in the shales and wavellite is thinly developed along certain bedding planes. The beds display a series of gentle folds. They contain scattered brachiopods	c.130

	Approximate thickness in feet
3. Light-grey limestones, for the most part calcite-mudstones but varying to fine-grained crincidal calcarenites with occasional dolomitic beds and thin shale partings. At certain levels the calcite-mudstones are distinctively banded while at others they have a nodular habit with nodules of pure limestone embedded in a matrix of calcareous mud. The development of chert is variable: in many of the upper beds it is absent, in lower beds it is present as thin nodular bands or as discrete nodules and in the lowest beds it is finely and uniformly distributed throughout. These beds contain compound corals and rare fragmental brachiopods. They are relatively hard and form a series of waterfalls.......	c.80
2. Unbedded, rusty, decalcified limestones with abundant small angular fragments of chert uniformly distributed. Occasional brachiopod fragments occur.....................................	30
1. Pale or rusty decalcified limestones (rottenstones) with bedded, nodular and fragmental chert probably composing 50 per cent of the rock, and occasional thin seams of white clay. Rare fossil fragments are found...........	25

Other outcrops in the shales are relatively unimportant: apart from a continuous strike section in an unnamed stream along the base of Slieve Anierin (a tributary of the Aghagrania River) they consist of small disconnected exposures limited to stream channels.

(b) Faunal Assemblages

The uppermost (described) shale beds of the Aghagrania sequence contain a rich and varied fauna. At certain levels *Goniatites granosus* is common, the specimens displaying the closely packed, beaded, spiral lirae and fine, intermediate transversals. In many however the minute tubercles are not preserved and the spiral striations appear smooth so that the shells are superficially like *Neoglyphioceras*. They are associated with abundant *Sudeticeras* spp and occasional specimens of *Dimorphoceras* sp. The goniatites are found with many kinds of molluscs which include *Posidonia membranacea* M'Coy, *Dunbarella* spp., *Chaenocardiola* sp., *Euphemites* sp. and the pleurotomariid *Glabrocingulum* sp. Brachiopods are represented by *Martinia* sp. and the mud-dwelling rhynchonellid *Leiorhynchoides* [*Leiorhynchus*] sp., corals by the small '*Emmonsia*' *parasitica*, and nautiloids by abundant orthocones.

The thick development of impure calcite-mudstones and calcareous shales above the Aghagrania Bridge sandstones contain fragmentary goniatites, probably *Goniatites falcatus* (resembling a form called *G.* aff. *falcatus* by Padget from Cuilcagh) and (?)Pronorites, which are associated with common specimens of *Posidonia becheri* Bronn, *Dunbarella* spp., coiled gastropods, straight nautiloids, and the brachiopods *Eomarginifera tissingtonensis*, *Productus* sp., *Martinia* sp. and *Orbiculoidea* sp. Plants also occur.

Lower beds in the sequence are poor in fossil remains. The massive, light-grey limestones contain Lithostrotion pauciradiale and the underlying rottenstones carry occasional cornute solitary corals, broken brachiopod shells (productids and spiriferids) and cryptostomatous bryozoans.

(c) Age Relationships

The association of G. granosus and Sudeticeras spp. supported by P. membranacea, confirms that the uppermost shales belong to the upper Bollandian (P_2) and suggests that they can be allocated to the lowest subzone P_{2a}.

Abundant P. becheri indicates a lower Bollandian (P_1)age for the underlying beds and is supported by the probable presence of G. falcatus, which is the index fossil of the P_{1b} subzone, and by Eomarginifera tissingtonensis, a characteristic D_2- D_3 subzone brachiopod.

It is difficult to date the lower part of the Aghagrania succession since there is a dearth of fossils. Conceivably the sandstones and the underlying impure limestones with shales belong to the crenistria subzone (P_{1a}), and the light-grey limestones and lowest strata, such fossils as they contain being common in the Cavetown Group, might be included in that Group and ascribed to the Upper Cracoean (B_2=D_1).

XI. FOSSIL LISTS

The following lists record the genera and species of corals and brachiopods collected personally from the rocks of the Carrick syncline and summarise their stratigraphical distribution.

The columns are numbered as follows:

1. Rockingham Sandstone Group
2. Kilbryan Limestone
3. Oakport Limestone Group
4. Ballymore Beds including small patch reefs
5. Croghan Limestone Group
6. Cavetown Limestone Group
7. Cavetown reef limestones
8. Aghagrania Shales

(a) Corals

	1	2	3	4	5	6	7	8
Aulopora sp.		x						
Chaetetes depressus (Fleming)						x		
Cladochonus crassus (M'Coy)(see Hill and Smyth 1937)					x		x	
'*Emmonsia*' *parasitica* (Phillips)						x		x
Michelinia cf. *favosa* (Goldfuss)			x					
-------- *megastoma* (Phillips)			x	x				
-------- *tenuisepta* (Phillips)	x	x		x	x	x	x	
(?) *Palaeacis* sp.				x				
Syringopora geniculata Phillips		x	x	x				
-------- cf. *ramulosa* Goldfuss			x	x				
-------- cf. *reticulata* Goldfuss			x	x				
-------- spp.							x	
Amplexus coralloides J. Sowerby				x			x	
Amplexizaphrentis enniskilleni (Edwards and Haime) and vars.		x		x	x	x		
Claviphyllum sp.					x			
Fasciculophyllum densum (Carruthers)		x		x				
------- *omaliusi* (Edwards and Haime)		x		x				
Hapsiphyllum konincki (Edwards and Haime) and vars				x		x		
Zaphrentites delanouei (Edwards and Haime) and similar forms		x		x				
Cyathaxoniicids	x	x	x	x	x	x		x
Caninia cornucopiae Michelin		x		x				

	1	2	3	4	5	6	7	8
-------- *subibicina* M'Coy				x	x	x		
'*Caninia*' sp. (large amplexoid form)			x	x				
Caninophyllum archiaci (Edwards and Haime) (see Lewis 1929, pp. 458-67)						x		
--------aff. *patulum* (Michelin) (see p.117)		x						
-------- cf. *patulum* (see Lewis 1927, pl.16, figs.4a-b and p.119)		x						
Siphonophyllia benburbensis (Lewis) and related forms				x	x	x		
------- *cylindrica* (Scouler)		x		x	x			
------- cf. *cylindrica* (compare Lewis 1927, pl.16, fig.2)		x		x				
-------- sp. (compare Lewis 1927, pl.16, figs. 3a-b)				x				
Siphonophylloid caniniids		x	x	x	x	x		
Caruthersella sp. (see pp. 117-118)				x				
Carcinophyllum simplex Garwood			x	x				
--------- spp.				x		x		
Clisiophyllum multiseptatum var. *rigidum* Lewis					x			
--------- spp.				x		x		
Cyathoclisia tabernaculum Dingwall (see p. 118)		x		x				
Dibunophyllum cf. *bristolense* Garwood and Goodyear					x			
--------- spp.					x	x		
Koninckophyllum ashfellense Garwood				x	x			
--------- *cyathophylloides* Vaughan (see Smyth 1937)				x				

	1	2	3	4	5	6	7	8
(?)-------- *divisum* Lewis					x			
-------- cf. *fragile* Garwood				x				
-------- *meathopense* Garwood				x				
-------- spp.				x	x	x		
Palaeosmilia cf. *murchisoni* Edwards and Haime			x	x				
Diphyphyllum fasiculatum Thomson				x				
-------- sp. (small)					x			
Lithostrotion affine (Fleming) and *related forms*				x		x		
-------- cf. *affine* (see p;119)				x		x		
-------- junceum (Fleming)						x		
-------- cf. *maccoyanum* Edwards and Haime (see p.119)						x		
-------- cf. *martini* Edwards and Haime (see p. 120)				x	x	x		
-------- *pauciradiale* (M'Coy) and *related forms*				x	x	x	x	
-------- aff. *pauciradiale* (see pp. 120-121)						x		
-------- *portlocki* Bronn						x		
-------- cf. *scoticum* Hill and diphymorphs (see p.121)				x		x		
-------- spp. (including those of the *affine-phillipsi* group (see p.119)			x	x		x		
Nemistium cf. *edmondsi* Smith			x					
Thysanophyllum pseudovermiculare (M'Coy)			x					

(b) Brachiopods

	1	2	3	4	5	6	7	8
Lingula sp.					x			
Orbiculoidea sp.								x
Daviesiella destinezi (Vaughan) and related forms (see Simpson 1953)			x	x				
------- sp.						x		
Megachonetes cf. *multidentatus* (M'Coy)	x	x	x					
------- spp. (broad papilionaceous forms)	x	x	x			x	x	
Plicochonetes cf. *crassistrius* (M'Coy) (see Vaughan 1905, p.294)					x	x	x	
Rugosochonetes cf. *hardrensis* (Phillips) (see Vaughan 1905, pp.293-4)		x	x	x	x			x
Antiquatonia insculpta (Muir-Wood)						x	x	
------- *hindi* (Muir-Wood) and similar forms				x	x	x		
------- sp.				x				
Argentiproductus margaritaceus (Phillips)					x	x	x	
----------*pectinoides* (Phillips)		x		x	x			
Avonia cf. *davidsoni* (Jarosz)				x	x	x		
--------- *youngiana* (Davidson)			x	x	x	x	x	
Buxtonia scabricula (Martin) and similar forms					x	x	x	
------- sp. (compare Muir-Wood 1928, pl.12, fig. 20)					x	x		
Cancrinella undata (Defrance)					x			
Chonetipustula carringtoniana (Davidson)					x	x	x	

	1	2	3	4	5	6	7	8
Dictyoclostus semireticulatus (Martin)						x	x	
-------- sp. (small)				x	x			
Dictyoclostids	x	x		x	x	x	x	
Echinoconchus elegans (M'Coy) and similar forms				x	x	x		
-------- eximius (Thomas)					x			
-------- *punctatus* (Martin) and similar forms		x	x	x	x	x		
-------- cf. *subelegans* (Thomas) (see p. 113)				x	x		x	
-------- spp.		x			x		x	
Eomarginifera cf. *derbiensis* (Muir-Wood)				x				
------- *tissingtonensis* (Sibly)								x
------- spp.		x			x			
Gigantoproductus crassiventer (Prentice)				x				
-------- spp.			x	x		x		
Krotovia cf. *aculeata* (Martin)				x	x	x		
-------- *spinulosa* (Sowerby) and similar forms				x	x	x		
Linoproductus 'cora mut. S_2' (Vaughan) (see pp. 114-115)			x					
-------- cf. *hemisphericus* (Sowerby)						x		
-------- sp. (Compare Vaughan 1905 pl.25, figs.4a-b, and see pp. 114-5)					x			
-------- spp.		x	x	x	x	x		
Overtonia fimbriata (J. de C. Sowerby)				x		x	x	
Plicatifera mesoloba (Phillips)				x		x	x	
-------- cf. *plicatilis* (J. de C. Sowerby)			x			x	x	

	1	2	3	4	5	6	7	8
Productus cf. *garwoodi* (Muir-Wood)					x			
-------- cf. *redesdalensis* (Muir-Wood)				x				
-------- spp.					x			x
(?)*Pugilus* sp.				x			x	
Pustula cf. *interrupta* Thomas		x		x	x			
(?)--------- *pilosa* Thomas					x	x		
--------- *pustulosa* (Phillips)				x				
--------- *pyxidiformis* (de Koninck) and similar forms		x		x	x	x	x	
Pustulids (including unidentified small forms)		x	x	x	x	x	x	
Sinuatella sp.				x				
Striatifera sp.						x		
Derbyia sp.					x			
Schellwienella cf. *aspis* Smyth					x			
--------- cf. *radialis* (Phillips)					x			
--------- spp.		x		x		x	x	
Schuchertella sp.					x			
Orthotetids	x	x	x	x	x	x	x	
Rhipidomella michelini (Leveille) and similar forms		x	x	x	x	x		
Schizophoria resupinata (Martin)		x		x		x	x	
-------- *resupinata* var. *gigantea* Demanet							x	

	1	2	3	4	5	6	7	8
Camarotoechia pleurodon (Phillips)					x	x	x	
-------- spp.	x	x		x				
Leiorhynchoides sp.								x
Pugnax pugnus (Martin)							x	
Stenocisma sp.				x				
--------- cf. *globulina* (Phillips) (compare Davidson 1858, 2, pl.24, 11a-c)					x		x	
Actinoconchus expansus (Phillips)		x	x		x			
--------- cf. *lamellosus* (Leveille)					x			
--------- cf. *planosulcatus* (Phillips)				x	x	x	x	
'*Athyris*' cf. *ingens* (de Koninck) (see p. 111)							x	
Cleiothyridina cf. *glabristria* (Phillips)		x						
-------- cf. *globularis* (Phillips)					x			
-------- cf. *roissyi* (Leveille) (see p. 111)		x		x	x			
Composita cf. *ambigua* (Sowerby) (see p. 112)				x				
-------- *ficoides* (Vaughan)			x					
-------- cf. *gregaria* (M'Coy) (see pp. 112-3)			x					
-------- *triloba* (M'Coy)			x					
Athyrids (undifferentiated)	x	x	x	x	x	x	x	
Brachythyris cf. *subrotundatus* (M'Coy)				x	x			
--------- spp.				x	x	x	x	
(?)*Davidsonina* sp.			x					

	1	2	3	4	5	6	7	8
Martinia cf. *glabra* (Martin)					x		x	
Martinia sp.						x	x	x
Phricodothyris *lineata* (Sowerby)				x				
--------- cf. *lineata* (Sowerby) (see pp. 115-6)				x	x			
--------- spp.				x		x	x	
Punctospirifer sp.				x				
Reticularia cf. *obtusa* (Sowerby)						x	x	
--------- spp.		x	x		x			
Spirifer cf. *bisulcatus* Sowerby							x	
--------- *convolutus* (Phillips) (compare Davidson 1858, 2, pl. 5 fig.12)							x	
'---------' *oblatus* (Sowerby)						x		
--------- cf. *princeps* M'Coy		x	x			x	x	
--------- spp.	x	x	x	x	x	x	x	x
Spiriferellina *octoplicata* (Sowerby) and vars.				x	x	x		
--------- sp.				x				
Syringothyris sp.			x		x	x		
Tylothyris *laminosa* (M'Coy) and related forms (see p. 116)	x	x	x	x	x	x	x	
Leptaena *analoga* (Phillips) and similar forms (see p. 114)		x		x	x	x	x	
Dielasma *hastata* (J. de C. Sowerby) and vars.				x	x	x	x	
--------- spp.		x		x	x		x	
Girtyella *saccula* (Martin)				x				

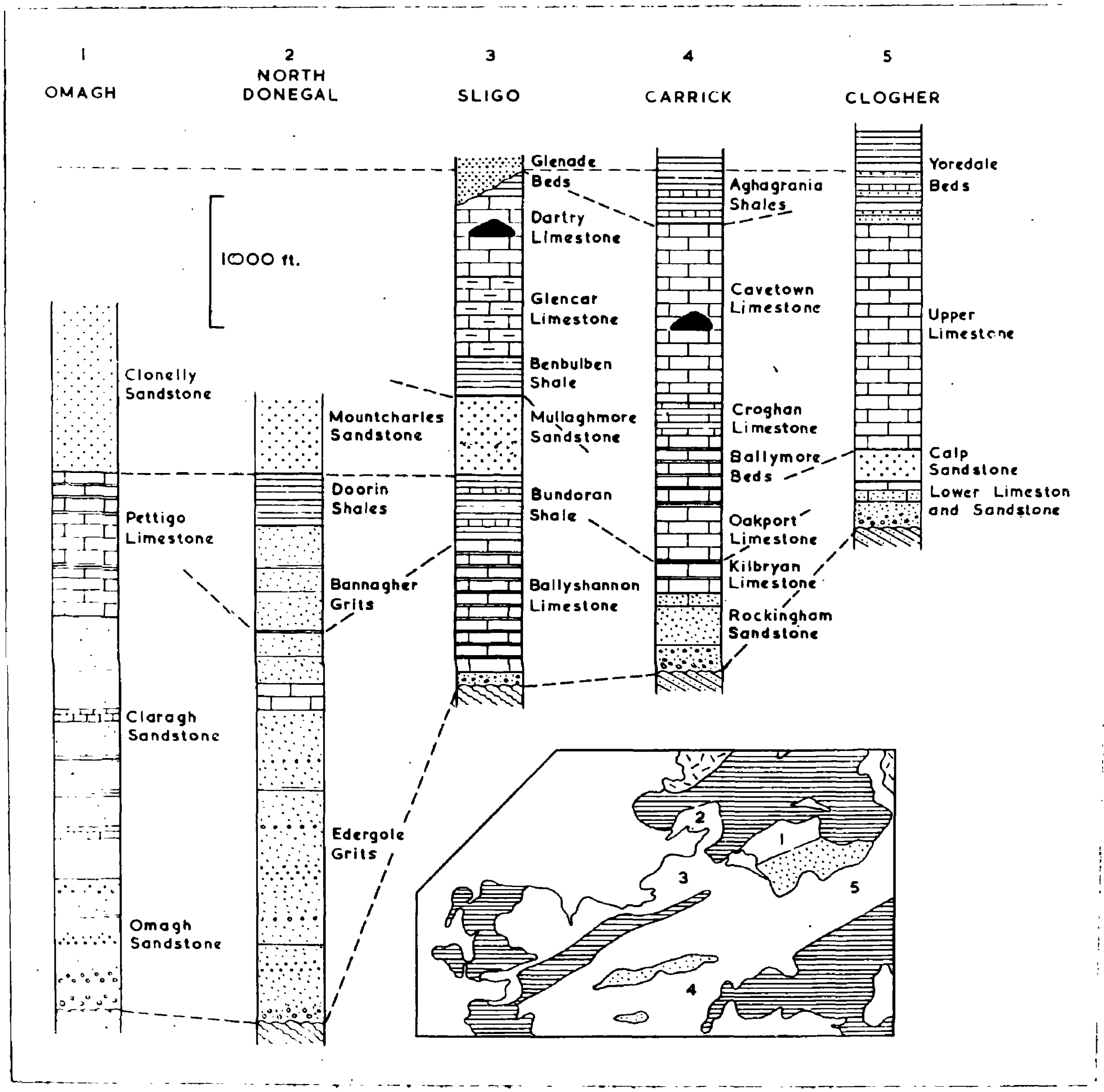

Fig. 9. Comparative sections summarising the proposed correlation of the Lower Carboniferous rocks in North-West Ireland

XII. COMPARISONS AND CORRELATIONS

It is difficult to correlate the Carrick succession precisely with that established by earlier workers in the ground to the north, but the broad relationships are summarised in fig. 9.

When the sequence is compared with that in the Donegal, Omagh and Sligo synclines (those north of the Ox Mountains) certain differences immediately become apparent. Firstly, there are wide contrasts in the comparative thicknesses of the lowest sandstones and succeeding limestones. Thus, for example, the Rockingham Sandstone Group and the Kilbryan Limestone, together totalling not much more than 600 ft., are probably the representatives of the Ballyshannon Limestone and conglomeratic basal beds of the Sligo - Ballyshannon ground (Oswald 1955, pp. 168-72) which, when traced towards Donegal and Lough Eske, display striking lateral changes and rapid increase in thickness, until, in the northern flanks of the Donegal syncline, they are represented by more than 3,000 ft. of sediments in which coarse delta-sandstones predominate (George & Oswald 1957, pp.   ). These beds equate with the Omagh and Claragh Sandstone Groups and Pettigo Limestone of the Omagh syncline which are developed to a comparable thickness (Simpson 1955, pp.393-400). Secondly, the Carrick sequence differs in not displaying recurrence of the sandstone facies in S_2 times. The Oakport Limestone Group is possibly the equivalent therefore of the Mullaghmore--Kildoney Sandstone of the Sligo--Donegal ground and the Ballymore Beds a more calcareous representative of the Benbulben Shale. Lastly, whereas the succession ascribed to the C_2S_1 zone is comparatively thin at Carrick, there is an increased thickness of massive D_1 limestones. These limestones contain thick reefs closely resembling in form and faunal content the Sligo reefs described by Oswald (op. cit. pp.177-9).

Broadly, therefore, north of the line of the Ox Mountains, in the composite trough stretching from Mayo to Omagh and beyond (George 1953, p.66), there accumulated a mixed series of sediments -- predominately limestones but with thick sandstones and shales -- probably to a thickness exceeding 8,000 ft. (idem. p.73); but to the south, in the Castlebar syncline (see discussion of Oswald, op. cit. p.186) and in the Carrick syncline, the thickness is appreciably less and the facies wholly calcareous. It would appear therefore that the narrow anticline of the Ox Mountains, actively rising during part of Lower Carboniferous times, was a major structural control on sedimentation. Not only did its growth have a profound effect on the thicknesses of the accumulating sediments in the Sligo ground (idem. fig.2) but its influence is further apparent in the contrasted thicknesses and facies of the beds on either side. The possibility cannot be excluded however that the Curlew Mountains axis may have acted as a supplementary ridge in more or less degree. Only in later Visean times was uniformity of facies established over the whole region as is indicated by the similar lithologies of the Dartry Limestone (idem. pp. 176-7), the limestones of the Bricklieve Mountains (north of the Curlew Mountains pericline) and the Cavetown Limestone Group.

The lower part of the succession in the Clogher area of Tyrone (Padget 1951, pp. 66-7) is thin compared with that at Carrick; and the presence of the mid-Visean 'Calp' sandstones makes a further difference. This is surprising since Clogher lies along the same depositional strike. In thickness and general lithology the upper part of the Clogher sequence is directly comparable with the Carrick development.

The Lower Carboniferous outlier in the south of the Isle of Man (Lewis 1927; 1930) provides a convenient link between northern Ireland and the Central Province of England. Recently Simpson (op. cit. pp. 401-2) has compared the Pettigo Limestone of the Omagh syncline with the lower part of the Isle of Man and North-West England (Garwood

1913, pp. 466-8) successions -- a comparison which may now be extended to include the lower part of the Carrick sequence, the faunal assemblages of which include a large number of Garwood's important brachiopods and corals.

Equally (if not more) striking however is the resemblance of the Carrick sequence to that in the Craven-Bowland lowlands. Thus, for example, in lithology and particularly with regard to fauna, there is an impressively close similarity to the Skibeden Shales-with-Limestones and the Draughton Limestones of the Skipton anticline (Hudson & Mitchell 1937) or with the Swinden beds, Toft Hill Limestone and Mallardale Shales-with-Limestones of the Swinden anticline (Hudson & Dunnington), 1945, pp. 201-2. These in turn are successfully correlated with the Clitheroe Limestone group and Worston Shales of the Clitheroe and Slaidburn districts (idem. pp. 207-10; Parkinson 1926, pp. 195-212; 1936, p. 295). George and Oswald (1957, pp.) and Hudson (in discussion of Oswald 1955) comment on the similarity of the Sligo--Donegal succession to that in the Craven lowlands and Turner (1937) has emphasised how the tectonic setting and sedimentation history of these lowlands are mirrored by those of the Dublin district. The relationship between the Avonian rocks of the greater part of northern Ireland and those of central and northern England is so close therefore that it is tempting to conclude they formed part of the same trough of sedimentation during much of Visean times.

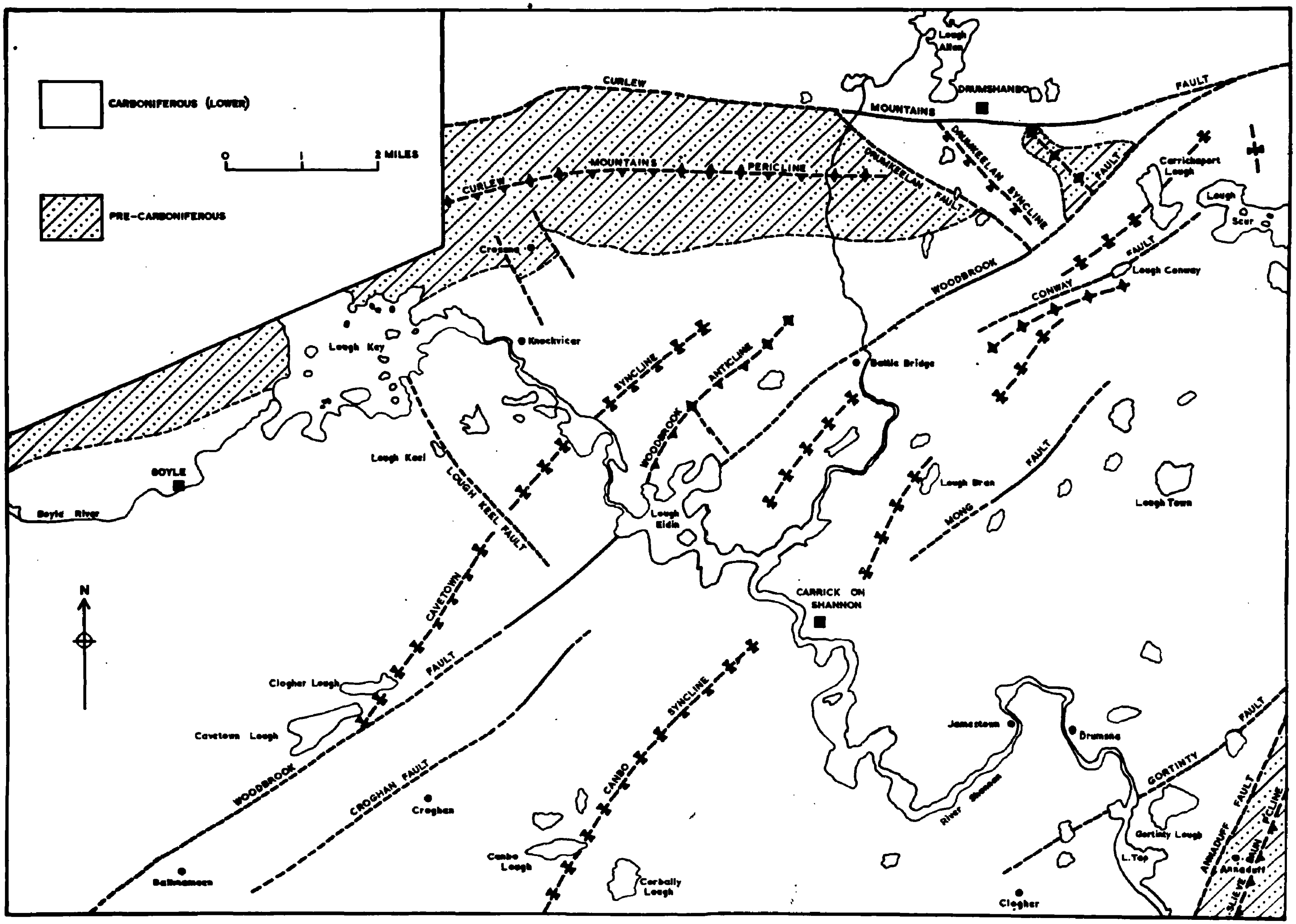

Fig. 10. Outline map of the principal structures in the Carrick syncline

XIII. STRUCTURE

The Carrick syncline is a broad composite downfold of caledonoid trend bounded to the north by the periclinal arch of the Curlew Mountains and to the south by a comparable upfold (although of notably different alinement) termed the Slieve Baun[4] pericline. Its essential structures may be resolved into a series of weakly asymmetrical pitching anticlines and synclines crudely arranged in echelon, traversed by a number of faults the most important of which are wrench faults. The major structural lines are indicated in fig. 10.

(a) Folding

(i) Folds north of the Woodbrook fault.

The structural complement of the Curlew Mountains pericline is the Cavetown syncline which preserves, in an unbroken sequence, strata ranging from the Rockingham Sandstone Group to the Cavetown Limestone Group. The closure of the fold is clearly delineated by the surface distribution of the divisions of the Oakport Group in the well exposed ground between Knockvicar and Cootehall

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[4] Slieve Baun is the most conspicuous of a range of hills formed by the Lower Palaeozoic rocks in the core of the pericline.

(fig. 4). Here dips are extremely shallow: indeed the wide outcrop of the calcite-mudstone beds demands that, unless there is drastic increase in thickness (and this seems unlikely from the behaviour of the beds in the limbs of the fold), they must be virtually horizontal where they underlie the ground about Oakport Lough. Variations in dip are more evident in the overlying *Linoproductus* beds however which locally are horizontal or inclined against the direction of pitch. In the vicinity of Clogher Lough more tightly folded limestones of the Cavetown Group define the synclinal core (fig. 5) and asymmetry is apparent in the unequal inclinations of the opposing limbs.

Southwards the Cavetown syncline is succeeded by the Woodbrook anticline but the continuity of this structure is broken by the Woodbrook fault. The essential form of the fold is nevertheless brought out south of Cootehall particularly by the lowest beds of the Oakport Group (fig. 4).

A shallow pitching anticline and its complementary syncline (the Drumkeelan syncline) of anomalous north-west and south-east axial trend are inferred to be developed across the nose of the Curlew Mountains pericline. The folds are not convincingly displayed (only the common limb is well exposed) but they are the simplest means of accomodating the scattered outcrops of sandstones and limestones in ground which is heavily glaciated.

(ii) Folds south of the Woodbrook fault.

South of the Woodbrook fault the regional structure is that of an asymmetrical syncline, the northern limb being the more steeply inclined; but the outcrops of the youngest beds — the Croghan Limestone Group and the Cavetown Limestone Group — indicate that within the broad synclinal core two distinct fold elements are present.

The Canbo syncline is an exceedingly shallow fold fashioned (at outcrop) almost wholly in limestones of the Croghan Series and particularly well-defined by the outcrop of the Pustula beds (fig. 12). These give rise to a gentle escarpment that provides some topographic expression of the structure. Like the Cavetown syncline it pitches gently to the south-west; but it also shows signs of north-easterly pitch and is probably a slightly elongate basin.

A pitch culmination separates the Canbo syncline from its northern analogue, which, in contrast, is a downfold compounded of a number of impersistent pitching anticlines and synclines seen in the Cavetown Limestone Group. The most obvious of the constituent folds are a syncline located south-west of Bran Lough which pitches gently to the north-north-west; an anticline (exposing limestones in the Croghan Group) and a complementary syncline pitching to the south-west in the ground north-west of Sheemore; and a syncline pitching to the north-east indicated by the bedded limestones in the Carrickaport reef mass. South of Lough Scur (in the Sheebeg ground) the regional strike is east-and-west, but north of the Lough patchy exposures afford evidence of folding along north-south axes. The intervening ground however is poorly exposed and relationships are obscure.

(b) Faulting

(i) The Woodbrook fault.

The Woodbrook fault stretching diagonally across the area from south-west to north-east is the largest and most important of the dislocations and has a profound effect on the surface distribution of the various limestone Groups.

The extent of the fault is uncertain. In the extreme south-west where there are thick superficial deposits its position is conjectural and in the north-east it probably joins the Curlew Mountains fault at a point about two miles north of Lough Scur.

In its throw the fault shows marked variability, due primarily to a difference in fold pattern on opposite sides. West of Lough Eidin it obliquely truncates the Cavetown syncline; and near Clogher separates the Cavetown Group in the synclinal core from the Croghan Group and upper Ballymore beds of the northern limb of the Canbo basin. The direction of effective downthrow is therefore to the north and the amount varies between 150 ft. and more than 1,000 ft. But in the vicinity of Woodbrook, the Oakport Group is contiguous with mid-Ballymore Beds so that the effective downthrow is reversed and reaches a maximum of 650 ft. The fracture parallels the northern shore of Lough Eidin where it cuts the pitching nose of the Woodbrook anticline (fig. 4). Farther east its approximate position is given by isolated exposures: a little to the east of Shanballybaun Lough the Rockingham Sandstone Group lies within a few hundred yards of the Cavetown Group; and at Battle Bridge quarries near Leitrim, limestones in the Cavetown Group are clearly much disturbed with the development of near-horizontal slickensides. Less than a mile south of Drumkeelan Lough the effects of the fault are convincingly demonstrated. It occupies a depression flanked on one side by calcareous sandstones of the Rockingham Group and on the other by massive, cherty grey limestones with <u>Lithostrotion pauciradiale</u> in the Cavetown Group, and about half a mile to the north-east similar sandstones strike and dip obliquely towards an escarpment formed by steeply inclined reef limestones. Thus eastwards from Woodbrook the fault consistently downthrows to the south by gradually increasing amounts and near Carrickaport Lough, where reef limestones are in juxtaposition with Old Red Sandstone, the maximum throw is at least 2000 ft.

The effects of the Woodbrook fault are consistent with its being a wrench fault of some considerable magnitude. Outcrops on either side of the fracture are discrepant, but it is possible that the limestones of the Cavetown Group, occupying the core of the Cavetown syncline and the Sheemore-Sheebeg outcrop, are displaced relics of the central outcrop of the Carrick syncline. If such a correlation is valid, the Woodbrook fault is then a sinistral shear of about eight miles displacement. But even these two areas are differentially folded and this discordance, and the general lack of structural congruity across the fault, justify the contention that the fault is intimately connected with the folding and probably developed contemporaneously in response to a single system of pressures. Abnormally steep dips - 35 to 80 degrees - characterise beds in immediate proximity to the fracture and suggest that a vertical component of movement accompanied the shearing effect in the process of growth. A steep hade is indicated by the straight course of the fault along the greater part of its length but between Lough Eidin and the point of junction with the Curlew Mountains fault its trend is slightly irregular.

(ii) The Curlew Mountains fault.

For almost its entire length the periclinal arch of the Curlew Mountains is bounded by a major dislocation (the Curlew Mountains fault) which serves to throw Old Red Sandstone in the core of the fold against Carboniferous limestones occupying a broad tract to the north. Within the area of the Carrick syncline the effects of the fault are manifest only in the Drumshanbo ground, where, trending east-west in contrast to the usual strictly caledonoid trend, it brings Old Red Sandstone and the lowest Carboniferous strata into contiguity with the reef limestones of the Cavetown Group.

The pattern of outcrops on either side of the fault is markedly different. The reef limestones dip consistently to the north and are succeeded by upper beds of the Cavetown Group and the Bollandian shales; but on the south structural continuity of the Old Red Sandstone anticline is broken by folds and faults which trend oblique to the dislocation and end abruptly against it. Thus the effective throw of the fault is consistently to the north and must everywhere exceed 1,700 ft.

Clearly the Curlew Mountains fault is not therefore a normal fault. It probably finds a place with the Woodbrook fault in a group of wrench fractures with considerable lateral displacements; although a detailed structural study of the disturbance may equally well reveal the presence of thrusting.

(iii) Minor faults north of the Woodbrook fault.

North of the Woodbrook fault there are a number of minor fractures directed approximately normal to that of the main dislocation.

The Lough Keel fault in the east of the Rockingham estate visibly displaces the outcrops of all limestone groups from the Kilbryan Limestone to the Ballymore Beds (see fig. 4) and has the effect of off-setting the closure of the Cavetown syncline. When traced to the north its effect on the outcrop of the basal sandstone is lost as it enters Lough Key. To the south it appears to die out before it reaches the Woodbrook fault, since the gentle escarpment, marking the junction of the Oakport Limestone Group and the Ballymore Beds in the southern limb of the syncline, is unbroken. The direction of downthrow is to the east and the vertical displacement is of the order of 50 ft.

There is no direct evidence for the Drumkeelan fault. Its presence is postulated as the simplest means of relating the Carboniferous sandstones and limestones of the anomalous Drumkeelan syncline to the Old Red Sandstone beds in the core of the Curlew Mountains pericline. The true relationship is probably much less simple for this triangle of ground between the Woodbrook fault and the Curlew Mountains fault may well be broken by a complex system of wedge faults.

(iv) Minor faults south of the Woodbrook fault.

The minor fractures developed south of the Woodbrook fault are like their northern counterparts in behaving as normal faults, but they contrast with them in trend which is always in approximate parallelism with the major dislocation.

Repetition of the escarpment formed by the *Pustula* beds (see p. 51) is clear evidence for the presence of the croghan fault in the ground near Ardglass House; and, although its position is conjectural in the intervening ground, the same fault probably causes a comparable displacement near Croghan village. The downthrow is to the north and probably does not greatly exceed 50 ft.

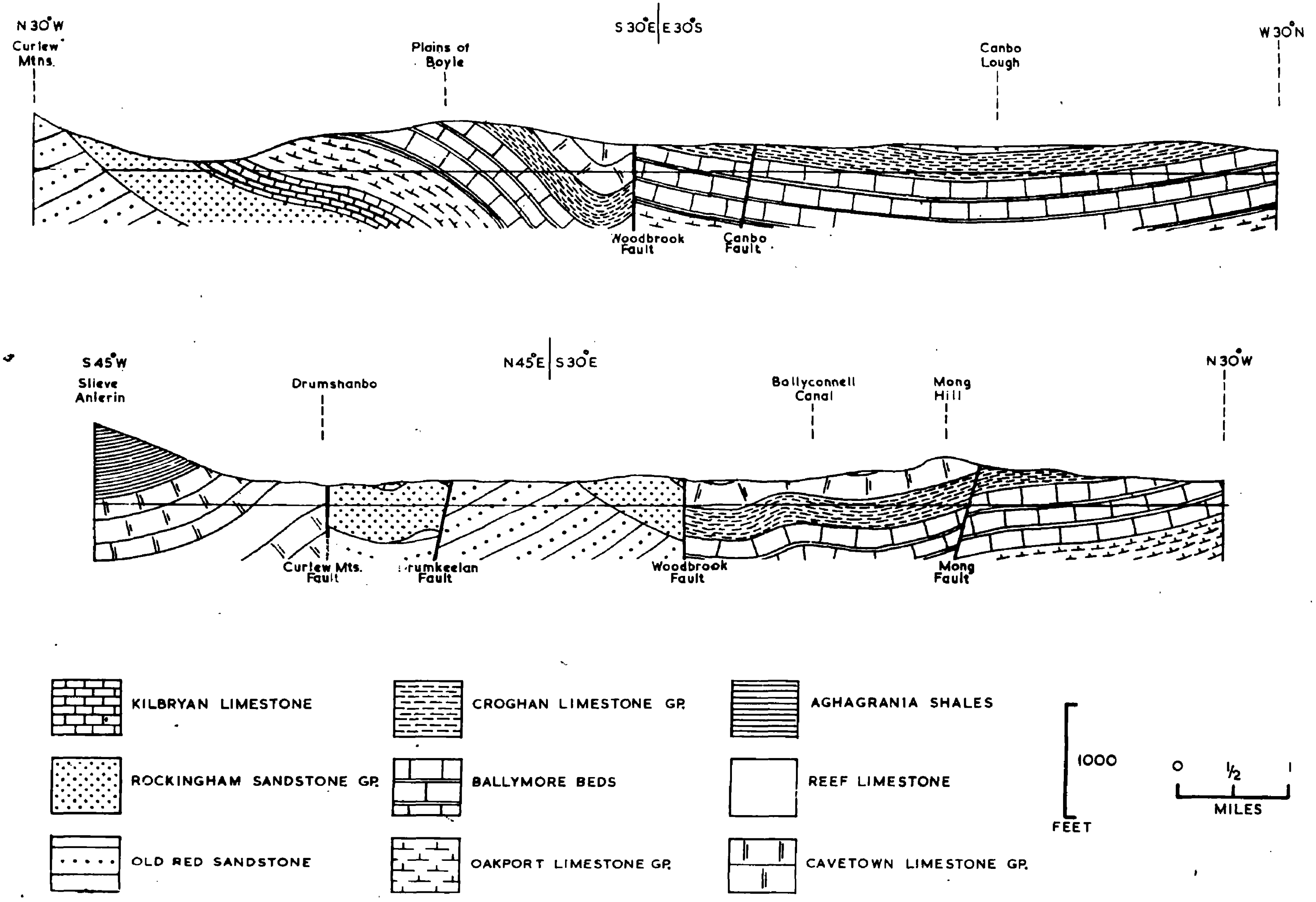

Fig. 11. Sections illustrating the structure of the Carrick syncline

North of Sheemore there is at least one fault which probably defines the southern boundary of the Carrickaport reef mass (in the Cavetown Group) and separates the underlying massive limestones from limestones of the Croghan Group. A single fault is, however, scarcely sufficient to explain the various stratigraphical levels seen in the isolated exposures of this ground.

Like the pericline of the Curlew Mountains, the Slieve Baun upfold is fault-bounded (by the Annaduff fault) on its northern flank. This is apparent north-east of Gortinity Lough, where the Rockingham sandstones, the Kilbryan Limestone and the lowest beds of the Oakport Group are progressively brought into contact with Lower Palaeozoic sediments or basal Carboniferous sandstones on the eastern, upthrown side.

The Gortinty fault is inferred to explain the progressive elimination of the Linoproductus beds and the calcite-mudstone beds in the ground immediately west of Gortinty Lough. The fault downthrows to the north and has a maximum throw of about 300 ft.

(c) Development of the Structures

In the Carrick syncline the main structures are gentle caledonoid folds and at least one sinistral wrench fault, the alinement of the fault being approximately parallel to that of the fold axes. There is evidence that growth of these structures took place contemporaneously and therefore they are inferred to be the product of resolution of a major compressive force, directed to the north, into two components at right angles; a compressive force directed north-westwards giving rise to the folds, and a horizontal shearing force directed north-eastwards giving rise to the fault(s). Resolution of the main force was brought about by its acting obliquely against (or being influenced by) foundational structures of caledonoid trend. The theoretical dynamics seem to be borne out closely by the Woodbrook fault; but, if the Curlew Mountains fault is a wrench fault, its east-west trend within the area indicates that either the major force was directed to the north-east or the anomalous trend has been induced by some unknown local circumstance. The sites of the major faults may have been pre-determined. For example Thirlaway (1951) concluded from gravity results that no Old Red Sandstone was present north of the Curlew Mountains fault - despite the fact that there are thousands of feet of it in the periclinal core and in the Fintona ground to the north-east. This implies that the fault was a major structural line in pre-

Carboniferous times and underwent posthumous movement.

Development of the Drumkeelan syncline and complementary anticline (the structures incongruously situated astride the pitching nose of the Curlew Mountains upfold) was probably due to buckling in the area wedged between the Curlew Mountains fault and the Woodbrook fault — an area which could react independently of those to north or south.

The age of the structures cannot be established with certainty; but it is highly probable that they originated during the period of Armorican earth movements. Evidence is wanting as to the relative age of the normal faults.

(d) Structural Comparison

The kinds of structures characteristic of the Carrick syncline are similar to those seen in other parts of north-western Ireland.

Simpson (1955) has described the Omagh syncline as a broad downwarp transected and rendered complex by a system of important caledonoid faults which are probably wrench faults "although the possibility of there being large vertical movements cannot be ignored". Minor folds (often strongly developed) appear to be closely related to movement along these disturbances, and there are subsidiary dip faults with a general north-south alinement.

Sinistral wrench faults cutting the Barnesmore granite of south Donegal are described by Leedal and Walker (1954) and recently George and Oswald (1957, p.) have shown that these faults bring about a comparable displacement of the Carboniferous rocks in the Donegal syncline.

An impressive superficial similarity exists between the Carrick structures and those in the southern region of the Midland Valley of Scotland where two broadly similar systems of faults are prominently developed; powerful caledonoid faults probably with sinistral displacements (Anderson 1951, p.92) and intimately connected with local folds the axes of which converge with the faults at a low angle, and north-west and south-east normal faults of later date, possibly Tertiary according to Anderson (op. cit. p.36), which usually terminate against the caledonoid disturbances. The major Scottish faults however seem to have had a considerably more complex history. Some afford evidence of initiation in proto-Armorican times and wide contrasts in the thickness of Lower Carboniferous sediments across the faults point to movements contemporary with Lower Carboniferous sedimentation. In these respects they differ from their Irish analogues.

XIV. PALAEONTOLOGY

(a) Brachiopods

'*Athyris*' cf. *ingens* de Koninck.

Plate 16(a)-(c)

Broad uniplicate athyrids, referable to the above species, are fairly common fossils in the reef limestones of the Cavetown Group. When compared with de Koninck's figure (1887, pt.6, p.20) the largest specimens are seen to be more transverse and to possess a more prominent median fold.

The majority of the specimens are decorticated and thus, uncertain of the true generic affinities of the species, I have retained de Koninck's original designation.

Cleiothyridina cf. *roissyi* (Leveille) and similar forms

Plate 17(a) - (d)

Spinous athyrids, referable to the genus *Cleiothyridina*, are common fossils in the limestones-with-shales of the Kilbryan Limestone and particularly so in the Ballymore Beds. The majority agree with *C. roissyi* (Leveille) as interpreted by Davidson (1858, 2, pl.18, figs. 8-11) but a number appear to be more closely related to the more expansiform *C. pectinifera* (Leveille). They are all however very different from the type (Leveille 1835, pl.2, figs.

18-20) which is a broad, dorsi-convex, uniplicate shell found commonly in the Tournaisian (George 1954, p. 314).

Composita ambigua (Sowerby)

Plate 18(a)-(d)

Parasulcate or weakly episulcate smooth athyrids (although some have pronounced growth lines anteriorly) occur rarely with abundant spinous athyrids in the Ballymore Beds. They appear to be Sowerby's Composita ambigua (1823, p.105, pl. 376) and most closely resemble in details of external shape the uppermost of his figured specimens. The majority are much less strongly plicate than those described by George (1954, pp.314-5) from the lower Visean limestones of Breconshire.

Composita cf. gregaria

Plate 18(e) & (f)

A smooth brachiopod resembling Composita but with a well developed median septum in the brachial valve is the characteristic fossil of the Composita bed. There is great variation in shell shape: a number have the distinctly sub-triangular shape of C. gregaria (M'Coy 1844, pl.22, fig.18; Garwood 1913, pl.51, fig.5) but others, externally, are like C. ficoides.

The form has strongly developed dental plates (fig. 18 (f)) -- a typical feature of the athyrids -- and a deep muscle scar in the ventral valve.

Garwood (ibid. p.571) had doubts about its true affinities but stated that Vaughan was of the opinion it might belong to the genus Cryptonella. In many respects it agrees with Cryptonella but significantly that terebratuloid genus is without a prominent median septum and has a well developed long loop.

Echinoconchus cf. subelegans (Thomas)

Plate 19(a) & (b)

A number of pustulids obtained from the mid-Ballymore beds, the Croghan Limestone Group, and the Cavetown reef limestones belong to the genus Echinoconchus and are referred to the species subelegans.

They agree with subelegans in the globose pedicle valve, gently concave dorsal valve, narrow incurved umbo, and style of ornament. They differ however in size, being considerably larger than the type with a disproportionate increase in the length relative to breadth. They are most nearly matched by the specimen from Poolvash, Isle of Man figured by Thomas (1914, pl.17, fig. 12). They also differ in possessing a shallow ventral sulcus and corresponding dorsal fold, and in the wide spacing anteriorly of the concentric spine-bearing bands.

Leptaena analoga (Phillips)

Plate 19(c) & (d)

Leptaenids are found throughout the calcareous succession and are almost certainly conspecific with Phillips's L. analoga (the type is from 'Bolland'). Vaughan's identification of the South West Province forms as L. analoga was based on Davidson's interpretation and description but it is doubtful if they are in fact Phillips's species.

Linoproductus 'cora mut. S_2' (Vaughan) and allied forms

Plate 20(a)-(h)

Recurrent seams of thin-shelled aspinous productids characterise the upper Oakport Limestone Group -- the Linoproductus beds. They clearly fall within Vaughan's 'cora' species group (1905, pp.290-1) and, although variable, the majority are certainly his S_2 mutation -- see pl. 20(a)-(e) and compare Vaughan (idem. p.290 and pl.25, fig.4).

Another form, also a member of the 'cora' group (Pl. 20(f)-(h)), is a common and diagnostic fossil of the Croghan Limestone Series (Pustula Beds). It closely resembles the specimen figured by Vaughan (idem. pl.25, figs. 4a-b) which, he said, is noteworthy for its extremely fine ribbing and which occurs in S_2 and D_1. The Irish specimens appear to be slightly broader however and retain the narrow, strongly arched, ventral umbo of the S_2 form, while the ears carry strong pleats and a number of spine bases (compare Davidson 1858, 2, pl.36, fig.4-4a).

In 1913 Productus cora mut. S_2 was named by Garwood (p.469 footnote) Productus corrugato-hemisphericus and in 1916 he figured this species (pl.15, fig.1.). It is very doubtful however from a comparison of the two figures (I have not yet been able to compare the types) if they are one and the same species; Garwood's figured specimen appears to be more transverse, more coarsely costate, and to have a broader, less well defined, ventral umbo. Moreover P. corrugato-hemisphericus is a species without nomenclatural status — a fact noted by George and Oswald 1957, p. .

Phricodothyris cf. lineata (Sowerby)

Plate 21(a)-(c)

Reticulate spiriferids of the genus Phricodothyris occur abundantly at certain levels within the Ballymore Beds. The majority are intermediate in shape between P. lucerna George and P. lineata. They possess the unequal biconvexity of P. lucerna, but the ventral umbo is of lineata type, being moderately incurved, fairly prominent, and "in dorsal view appears elevated in characteristic fashion above the hinge line" in (George 1932, p.544).

A number of the smaller shells are malformed (see Reed 1893, and George ibid. p.543).

Tylothyris laminosa (M'Coy) and related forms

Plate 22(a)-(d)

Tylothyrids are found throughout the succession from the Rockingham Sandstone Group to the massive crinoidal and reef limestones of D_1 age.

The majority accord with the emended description of *T. laminosa* (M'Coy) (see North 1920, p.197) except that they are consistently larger and appear intermediate between North's γ 'mutation and those described from the high Tournaisian beds of Hook Head by Smyth 1930, p.559. They do not reveal the extremely acute cardinal extremities of the Hook forms (idem. pl.15, figs. 10-12) perhaps because of imperfect preservation. Variation is marked: for example specimens from one locality within the Ballymore Beds display a range of lateral profiles comparable with that illustrated by North (op. cit. figs. 4a-c). Certain shells from the Cavetown Limestone Group have a number of features in common with *T. subconica* (Martin)

Similar forms, exhibiting a comparable degree of variation, occur at Streedagh Point (Ballyshannon

Limestone) — Oswald (1955, pp. 170 & 172).

(b) Corals

Caninophyllum aff. *patulum* (Michelin)

Plate 23(a) & (b)

Large trocho-cylindrical caniniids exhibiting a marked cyathophylloid trend and clearly belonging to the genus *Caninophyllum* are common in (and apparently limited to) the Kilbryan Limestone. They differ from *C. patulum* (Salee 1910, p.39, pls. 6-8) in their minor septa being vestigial or absent, and in their markedly greater diameter in the adult stage. The majority agree with Vaughan's 'closely septate form' from Burrington Coombe 'diagnostic of γ' (Vaughan 1911, p.374, pl.30, fig.6a) except in diameter in which respect they resemble the figures of *C.* aff. *patulum* from the *Linoproductus* Beds of Hook Head (Smyth 1930, pl.16, figs. 2-3).

Lewis (1927) described and figured a specimen of *Caninia* cf. *patula* from the basal beds of the Kilbryan Limestone at Cleene. This form possesses short but distinct minor septa and is therefore more closely similar to Michelin's type.

Caruthersella sp.

Plate 24(a) & (b).

Carcinophyllid corals, apparently falling within the genus *Caruthersella*, occur in the limestones-with-shales of the mid-Ballymore Beds. They resemble the genotype -- *Carruthersella* *compacta* Garwood -- particularly in details of the complex central column, but differ in having a marginal zone without a development of lonsdaleoid dissepiments in the ephebic stage. The exial ends of the major septa are usually flexed.

Rolled specimens, probably of the same form, occur in the Pettigo Limestone of the Omagh syncline — Simpson (1955, p. 399).

Cyathoclisia *tabernaculum* Dingwall

Plate 24(c) & (d)

Nucleate aulophyllids, referable to the genus *Cyathoclisia*, are found occasionally in the Kilbryan Limestone and in the Ballymore Beds. They agree with the type species, *C.* *tabernaculum* Dingwall (1926, p.12), in the long clearly defined cardinal fossula, the long distally flexed major septa continuous with the septal lamellae, the long minor septa, and the complex dense central column.

The species is normally regarded as diagnostic of γC_1 but Smyth (1930, p. 544) found it in C_2 beds at Hook Head and it has been recorded from S_1 in Pembrokeshire. These occurrences therefore preclude its use as a Tournaisian marker fossil.

Lithostrotion cf. affine (Fleming)

Plate 25(a)

Colonies of fasiculate dendroid lithostrotiontids, agreeing with L. affine in all characters except the number of major septa, which is consistently 23 as opposed to the usual 30-32, have been obtained from the mid-Ballymore Beds and from the Cavetown Limestone Group.

Lithostrotion affine-phillipsi group

This conveniently descriptive term (used by Smyth 1925, p. 148) covers dendroid lithostrotiontids occurring in the upper part of the Cavetown Limestone Group in which the corallites vary considerably in size, the largest closely similar to those of L. affine and having the anastomosing habit of L. phillipsi Edwards and Haime.

Lithostrotion cf. maccoyanum Edwards & Haime

Coralla of small cerioid lithostrotiontids occur occasionally in the Cavetown Limestone Group (division (ii) of p.60) and are referred to the above species. They differ from the original description in having more numerous septa (the average number of major septa is 16 as opposed to 10-12) and a greater diameter of the corallites (average 4.5 mm. as opposed to 3-4 mm.). In these features they are intermediate between L.

maccoyanum s.s. and L. portlocki Bronn.

Lithostrotion cf. martini Edwards & Haime

Plate 26(a) & (b)

The great majority of the lithostrotiontids found in the upper part of the Ballymore Beds are closely similar to L. martini.

They have a thin striate epitheca, an average corallite diameter of 9.1 mm. (range 7.5-11.5 mm.) and an average number of major septa 27 (range 25-32) alternating with short minor septa extending just beyond the dissepimentarium. The major septa are however consistently shorter than in L. martini s.s. (with the exception of the counter-cardinal septum which unites with the thin lenticular columnella), seldom exceeding a half to two thirds of the radius of the corallites in length (compare Edwards & Haime 1850-4, p.197, pl.40, fig.2). In addition a third series of dissepiments is often present and the tabulae are more acutely conical than is indicated by the description and figures in the above monograph.

Lithostrotion aff. pauciradiale (M'Coy)

Lithostrotiontids apparently intermediate between L. pauciradiale and L. junceum (Fleming) occur in the upper part of the Lithostrotion pauciradiale reef and in the immediately succeeding limestones. They differ from the former species in the diameter of the corallites which ranges from 3.3 mm. to 4.3 mm., in the number of major septa which ranges from 16 to 19, and in the limited number of corallites that carry the characteristic single series of dissepiments.

Lithostrotion cf. scoticum Hill

Plate 25(b) & (c)

A group of fasiculate phaceloid or dendroid lithostrotiontids directly comparable with L. scoticum characterise the Ballymore Beds. They agree with L. scoticum in the epithecal characters, in the variable diameter of the corallites (from 5 mm. to 10 mm. -- average 6.5 mm.), and in number of major septa (22-28 — average 26) which alternate with short minors projecting just beyond the dissepimentarium. The principal aberrant biocharacter is the length of the major septa which is consistently greater than a half to two thirds of the radius of the corallites, while the counter cardinal septum often extends to the thin lenticular columella (compare Hill, 1941, pp. 173-4). In addition the dissepimental tissue tends to be irregular and more elaborate than in the type (a well developed endotheca is usually present), and the tabulae tend to be more acutely conical in their disposition.

(c) Trilobite

Phillipsia cf. scabra Woodward

Plate 22(e)

A number of well-preserved detached pygidia, resembling P. scabra Woodward (1883, pp.43-4, pl.9, fig. 5b) in general form, were recovered from the mid-Ballymore Beds. In detail however the form is considerably different from that species principally in relative dimensions, width of the pygidial border, and ornament, and it may well belong to a new species. The cephalon and the thorax are, however, unknown.

A typical pygidium is wider than long (10.5 mm.: 8.5 mm.) with a well defined axial lobe less than one third the width of the pygidium anteriorly, and consisting of fourteen firmly fused somites and two lateral (pleural) lobes each of ten somites. The axis, subtrapezoidal in cross section, extends the full length of the segmented portion of the pygidium and is markedly elevated, decreasing slightly in elevation and in width to a blunt rounded termination. The pleural lobes are gently arched and sharply differentiated from a well defined broad (1.7 mm.) gently convex flange (pygidial border). Ornament consists of rows of tubercles. They are generally nine in number on the crest of an axial somite, tending to decrease in size and become laterally contiguous with decreasing width. The broadest somites of the lateral segments carry twelve tubercles, but these decrease in number with decreasing width until the most posterior somite bears only a single protuberance. The rows of tubercles are continuous across the pygidial border, showing a gradual reduction in size towards the posterior edge where they are supplemented in the intertuberculate zone by fine granules, irregular in size and distribution.

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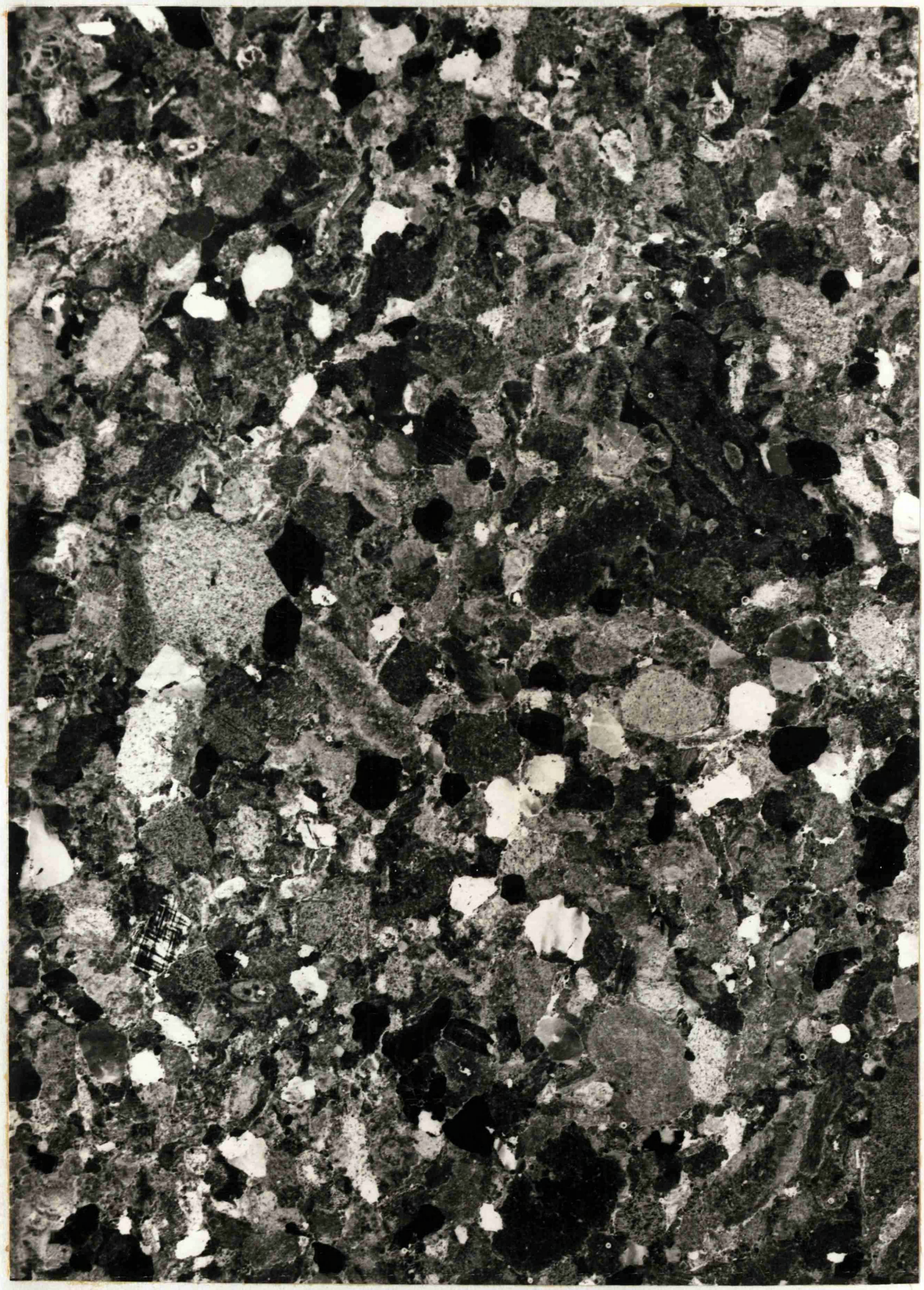
PLATE 1.

EXPLANATION OF PLATE 1.

Calcareous sandstone. Composed of approximately equal proportions of crinoid, shell and bryozoan fragments with scattered foraminifers and subangular and angular grains of quartz and felspar (including microcline). Top of the Rockingham Sandstone Group. Quarry 1 mile south of Drumkeelan Lough. X 17. The photograph is a negative.

PLATE 2.



EXPLANATION OF PLATE 2.

Sandy limestone. A typical example of the basal beds of the Kilbryan Limestone. The organic debris includes fragments of crinoids and shells and foraminifers throughout which is scattered numerous detrital grains of quartz and felspar. Quarry near the Quarters, Rockingham estate. X 18. The photograph is a negative.

PLATE 3.

EXPLANATION OF PLATE 3.

Oolitic limestone. Many small organic fragments (mostly of brachiopods, bryozoans and crinoids) and foraminifers (often in considerable numbers), with a single oolithic skin which is devoid of recognisable structure, are characteristic of the 'oolites' immediately below the calcite-mudstone beds (Oakport Group). They are set (together usually with a few shelled ooliths) in a matrix of clear recrystallised calcite. Quarry 2/3 mile east of Cootehall Lough. x 16. The photograph is a negative.

PLATE 4.

EXPLANATION OF PLATE 4.

Algal limestone. Composed largely of filamentous algal colonies which are seen to grade into calcite-mudstone which has resulted from disintegration of the algal tissue. Calcite-mudstone beds of the Oakport Group. Lisserdrea (north) quarry, near Boyle. X 16. The photograph is a negative.

PLATE 5.

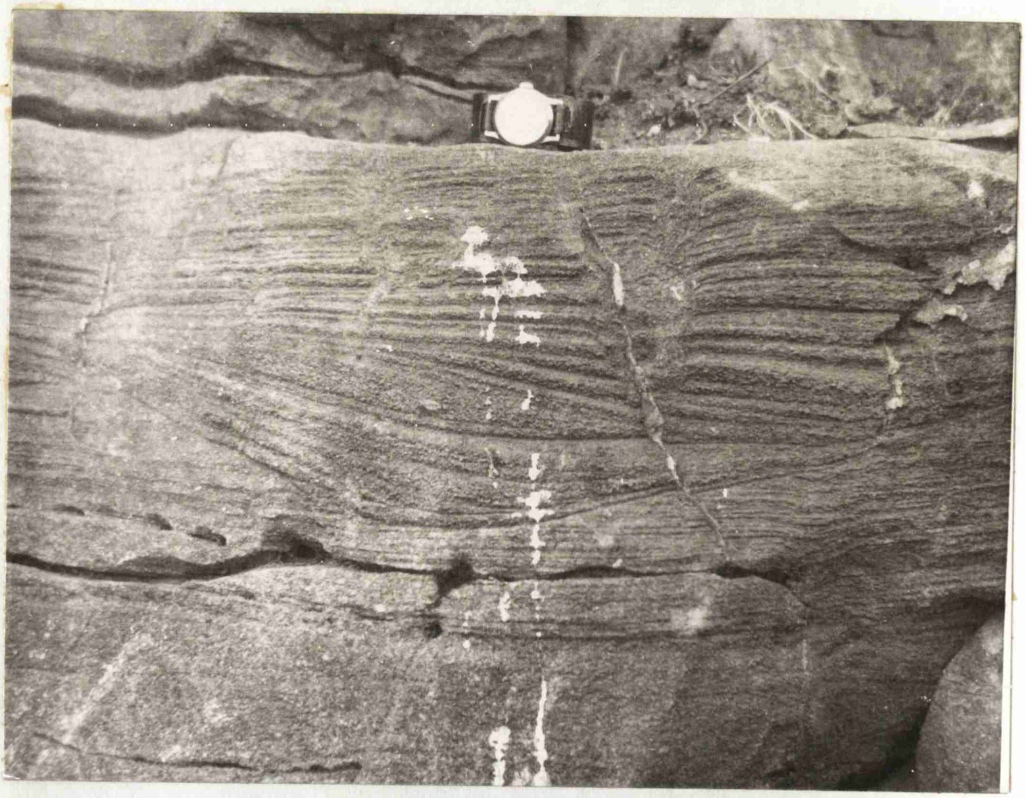
EXPLANATION OF PLATE 5.

Calcite-mudstone. The lithology of this limestone illustrates the mixed character of many of the calcite-mudstones of the Oakport Group. Conspicuous crinoid and mollusc shell fragments are embedded in a base of calcite-mud which is composed mainly of disintegrating algal tissue (in places fine tubular structure is still to be recognised). Quarry 200 yards north of Errironagh Lodge, Rickingham estate. X 12. The photograph is a negative.

PLATE 6.

(a)

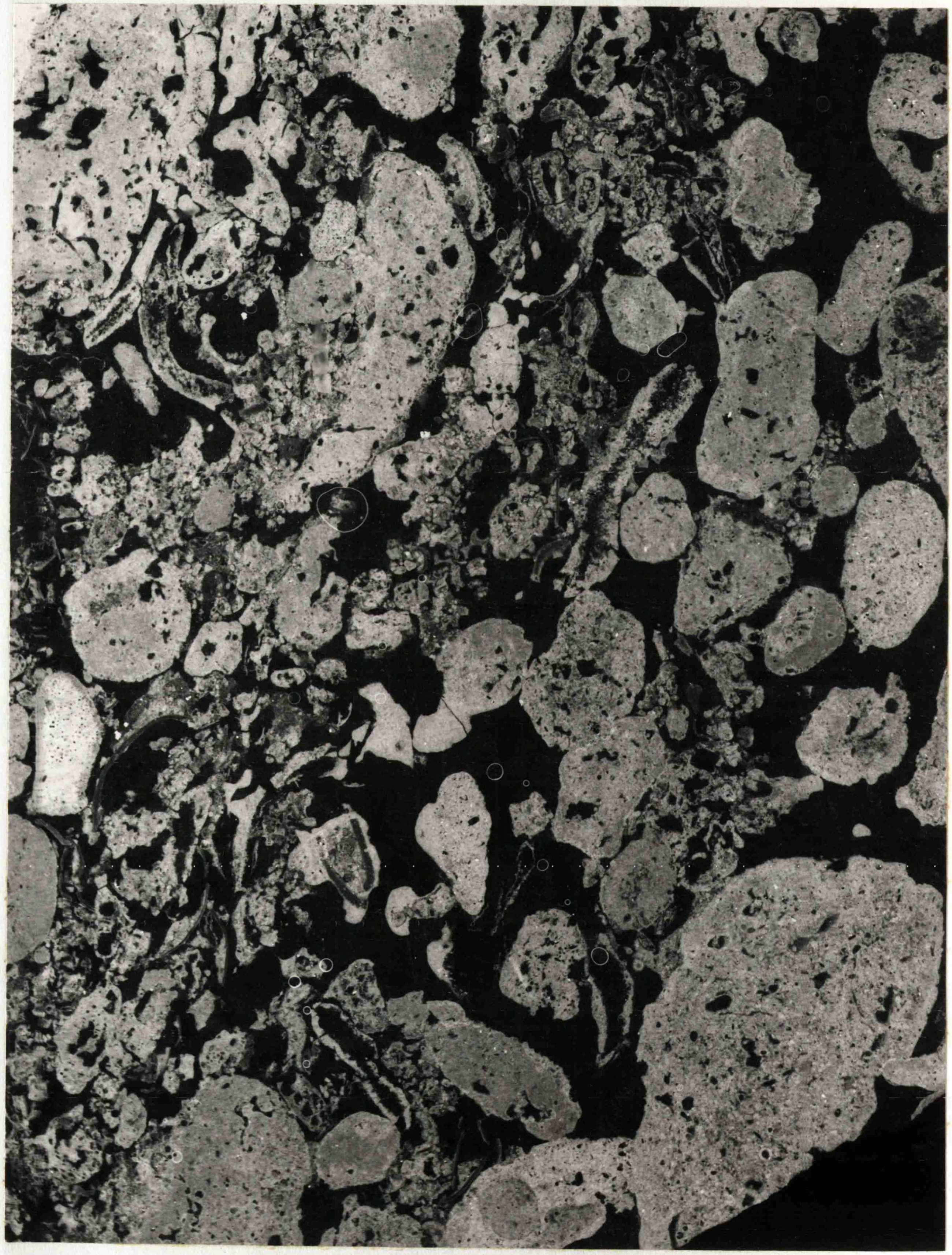
(b)



EXPLANATION OF PLATE 6.

(a) & (b) False bedding in crinoidal oolite. Near the top of the Linoproductus beds (Oakport Group). Quarry at Clogher, near Drumsna.

PLATE 7.



EXPLANATION OF PLATE 7.

Algal limestone. Large 'clots' of disintegrating algal tissue together with mixed organic fragments set in a recrystallised clear calcite matrix. Calcite-mudstone beds (Oakport Group). Letfordspark Quarry, Boyle. X 13. The photograph is a negative.

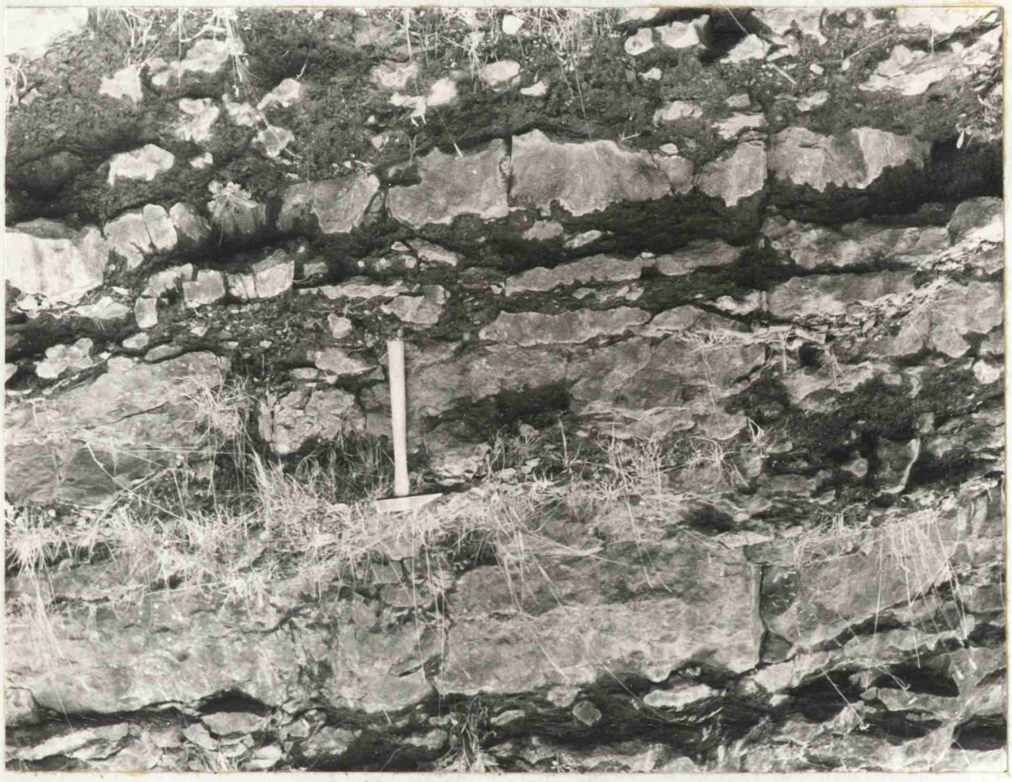
PLATE 8.

EXPLANATION OF PLATE 8.

Bioclastic limestone. Composed of fragments of crinoids, shells and algal colonies, ostracods, sponge spicules and a host of varied foraminifers including ammodiscids, archaediscids, erlandiids, nodosariids and plectogyrids. This is the typical lithology of the Syringopora beds (Ballymore Beds). Crag, 1 mile south of Glencarne House, Ardcarn. X 10. The photograph is a negative.

PLATE 9.

(a)



(b)

EXPLANATION OF PLATE 9.

(a) The nodular limestones and thick shales are characteristic of the mid-Ballymore Beds. Woodbrook quarry.

(b) Coral limestone. Composed mainly of giganteid caniniids and fasiculate lithostrotiontids. Upper Ballymore Beds. Knockarush quarry, Boyle.

PLATE 10.

EXPLANATION OF PLATE 10.

Oolitic bioclastic limestone. Brachiopod spines, trepostomate bryozoans, crinoid fragments and <u>Koninckopora</u> sp. are prominent among the organic constituents. Many of the fragments are surrounded by one or more oolithic shells in which radial fibrous structure can readily be discerned. A few of the ooliths are penetrated by well-formed crystals of authigenic quartz. The matrix is recrystallised calcite. <u>Pustula</u> beds (Croghan Group). Crag, 2/3 mile east-south-east of Cashel Cross Roads, Carrick. X 15. The photograph is a negative.

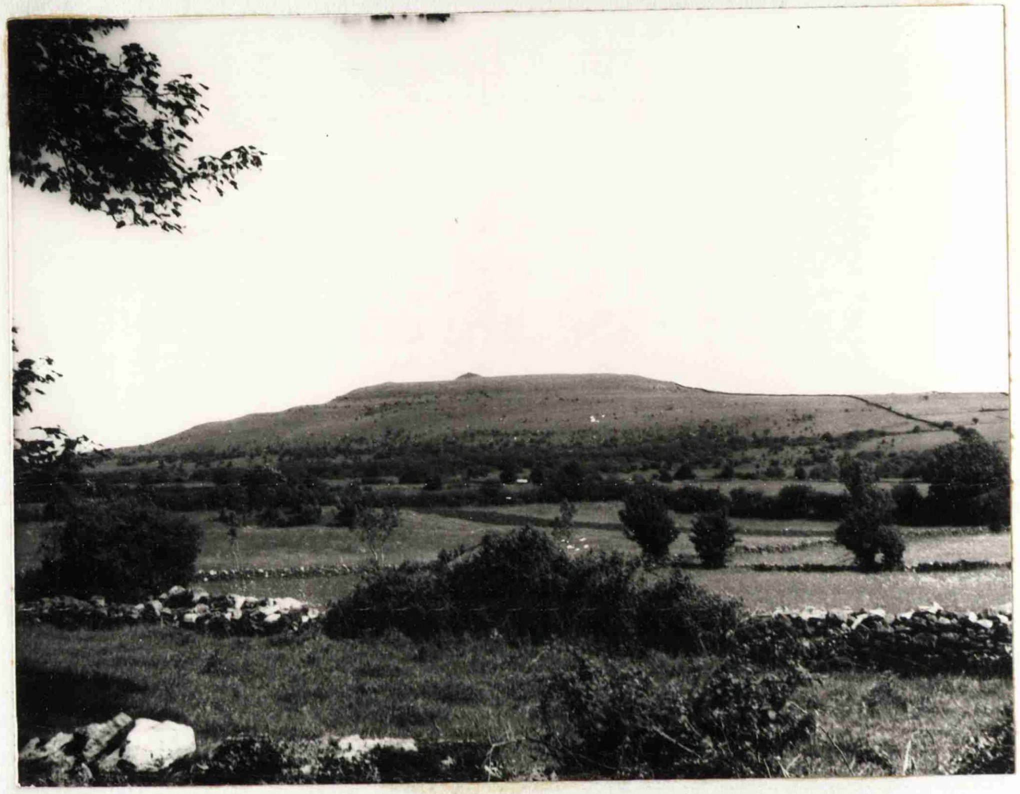
PLATE 11.

EXPLANATION OF PLATE 11.

Selectively dolomitized calcite-mudstone. 'Fragments' of unaltered calcite-mudstone surrounded by a more coarsely crystalline dolomitized 'matrix' gives the appearance of a pseudobreccia. Cavetown Limestone Group. Quarry 2/3 mile south of Carrickslavan Lough, Kiltoghert. Natural size.

PLATE 12.

(a)



(b)

EXPLANATION OF PLATE 12.

(a) Sheemore Hill. A terraced outlier in limestones of the Cavetown Group, 4 miles north-east of Carrick.

(b) Cherty limestones. Large irregular chert nodules in the lower limestones of the Cavetown Group. Mong hill, Kiltoghert.

PLATE 13.

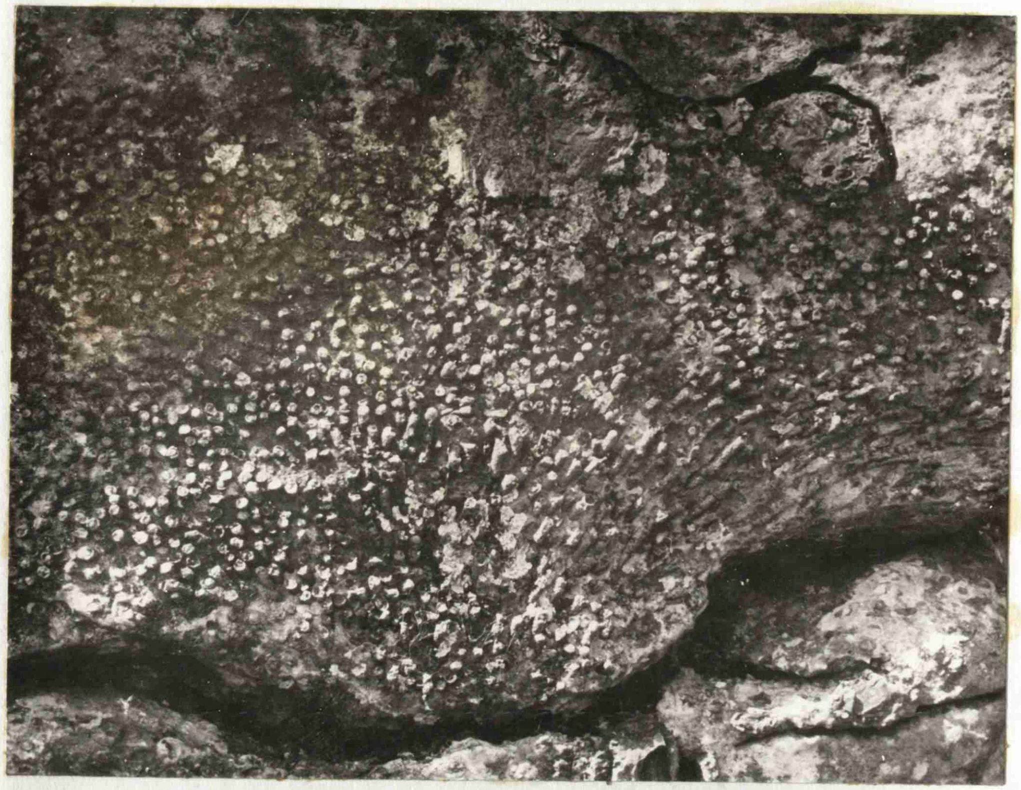
EXPLANATION OF PLATE 13.

Bioclastic limestone. Composed of trepostomate bryozoans, crinoids, foraminifers, brachiopod spines and sponge spicules embedded in clear recrystallised calcite. In its mixed organic-fragmental character and evenness of grain, this limestone is typical of the beds immediately overlying the *Lithostrotion pauciradiale* beds in the Sheemore-Bran Lough ground. Windmill stump, Mong hill, Kiltoghert. X 15. The photograph is a negative.

PLATE 14.

(a)

(b)



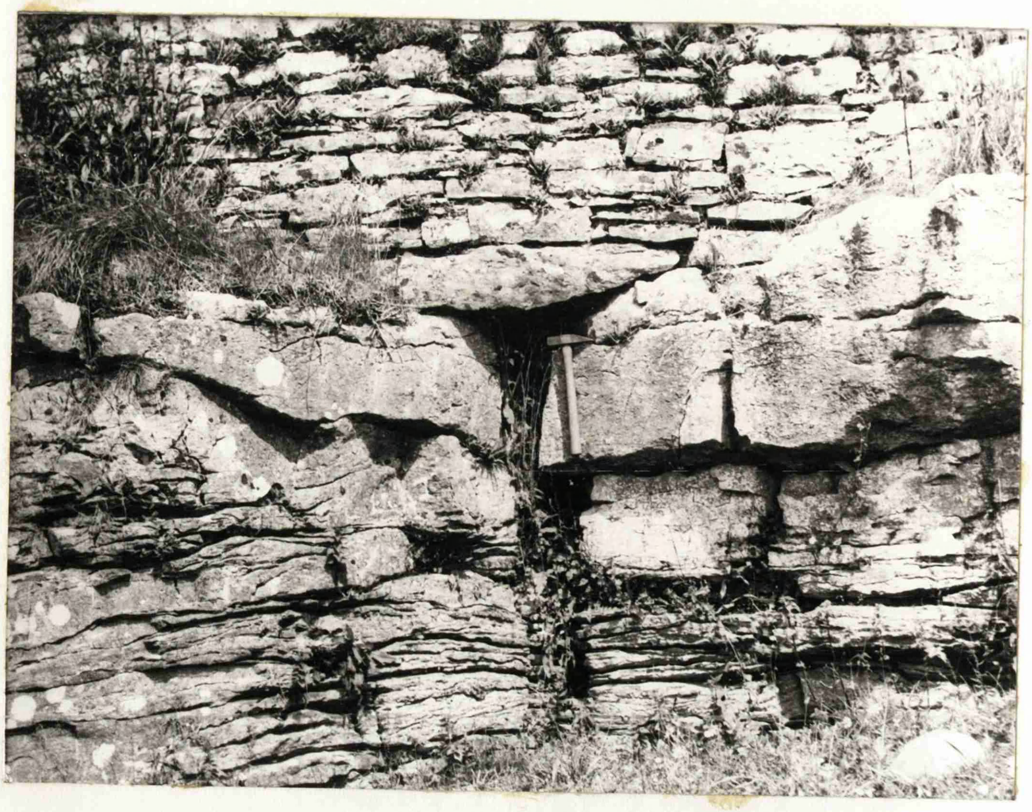
EXPLANATION OF PLATE 14.

(a) & (b) Coral limestones. Widely spread branching colonies of fasiculate lithostrotiontids in the Lithostrotion pauciradiale reef, (Cavetown Group). Bluff, 300 yards north of Clogher Lough, Cavetown. Scale: the diameter of a corallite is about 5 mm.

PLATE 15.

(a)

(b)



EXPLANATION OF PLATE 15.

(a) Low mound caused by a patch reef in the Ballymore Beds. Plains of Boyle, 1 mile north of Rathdiveen Lodge, Rockingham.

(b) Contact of reef and bedded limestones. Sharp junction (at bottom of hammer shaft) between reef limestone (above) and well-bedded limestones with tabular chert nodules of the Cavetown Group. Quarry in Keshcarrigan village.

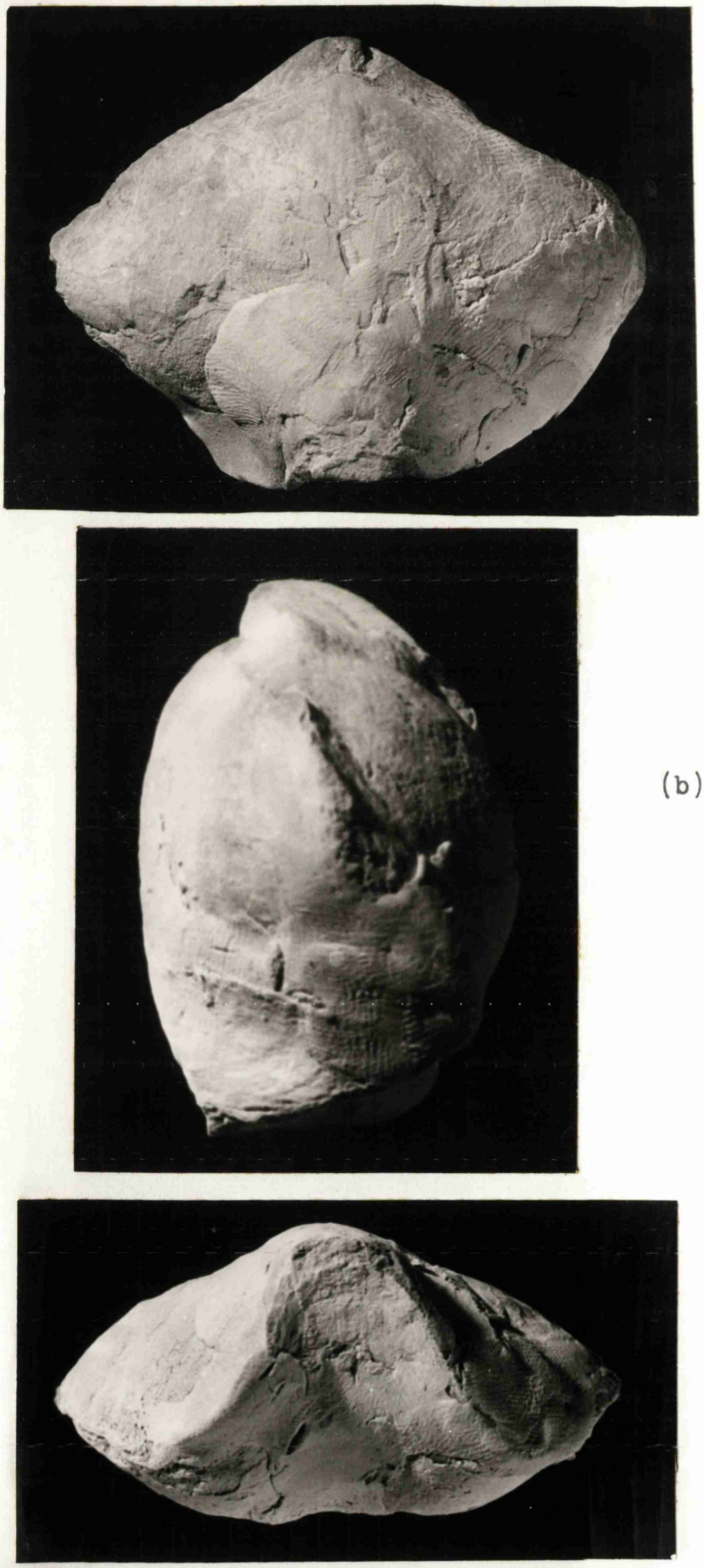


PLATE 16.

EXPLANATION OF PLATE 16.

'*Athyris*' cf. *ingens*

(a) Dorsal view of a large specimen (restored)
(b) Lateral view of the same specimen.
(c) View of the anterior margin of the same specimen showing the median plication.
(All X 1½).

PLATE 17.

(a)

(b)

(c)

(d)

EXPLANATION OF PLATE 17.

Cleiothyridina cf. roissyi

(a) Dorsal view of a specimen showing trace of the median septum in the brachial valve.
(b) Lateral view of the same specimen.
(c) Dorsal view of a more expansiform specimen showing the small foramen and remnants of the spiny investment of the shell.
(d) Lateral view of the same specimen. (All X 2).

PLATE 18.

(a)

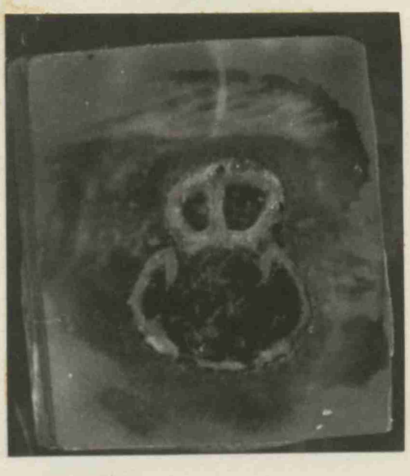
(b)

(c)

(d)

(e)

(f)



EXPLANATION OF PLATE 18.

Composita ambigua

(a) & (b) Dorsal view and view of the anterior margin respectively, showing the prominent growth lines anteriorly and weakly episulcate condition of the commissure. X 2.
(c) & (d) Dorsal view and view of the anterior margin of a less strongly plicate specimen. X 2.

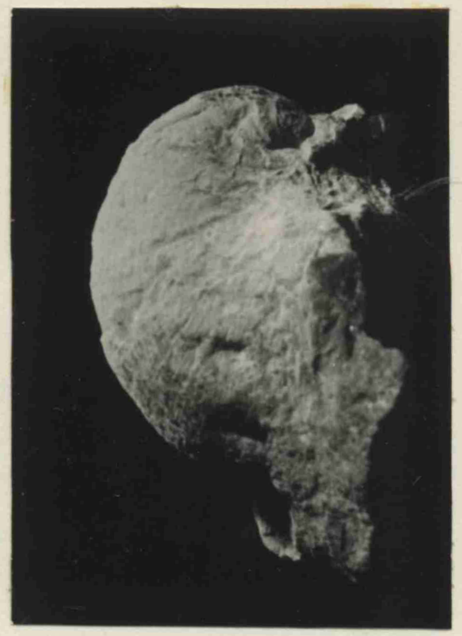
Composita cf. *gregaria*

(e) View of the interior of the dorsal valve of a small specimen showing the prominent median septum. X 6.
(f) Transverse section at 3 mm. below the ventral umbo showing the median septum and remnants of the dental plates. X 2.

PLATE 19.

(a)

(b)



(c)

(d)

EXPLANATION OF PLATE 19.

Echinoconchus cf. subelegans

(a) Ventral view showing the narrow umbo and the broad, widely spaced, spine-bearing bands. X 2.
(b) Lateral view of the same specimen. X 2.

Leptaena analoga

(a) & (b) Ventral and lateral view respectively showing the well-marked, concentric rugae and fine costae. In possessing a sharp geniculation and broad anterior and antero-lateral flange, this specimen is closely similar to the type. X 1½.

PLATE 20.

(a)

(b)

(c)

(d)

(e)

(g)

(f)

(h)

EXPLANATION OF PLATE 20.

<u>Linoproductus</u> '<u>cora</u> mut. S_2'

(a) Ventral view.
(b) View showing the transverse profile of the pedicle valve.
(c) View showing the transverse profile of the brachial valve.
(d) & (e) Two views of a more strongly arched specimen.

<u>Linoproductus</u> '<u>cora</u>' (D_1 form)

(f) Ventral view showing the characteristic ribbing, narrow umbo and ears with strong pleats.
(g) View showing the transverse profile of the pedicle valve, the incurved umbo and strong ear pleats.
(h) View showing the longitudinal profile of the pedicle valve.

(All natural size).

PLATE 21.

(a)

(b)

(c)

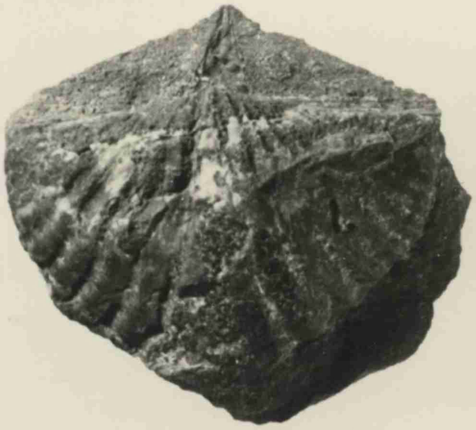
EXPLANATION OF PLATE 21.

Phricodothyris cf. *lineata*

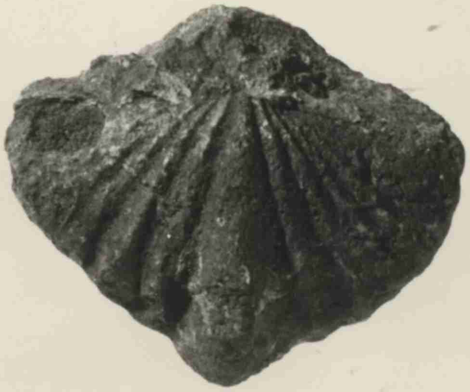
(a), (b) & (c) Dorsal, ventral and lateral views respectively of a malformed specimen. X 2.

PLATE 22.

(a)

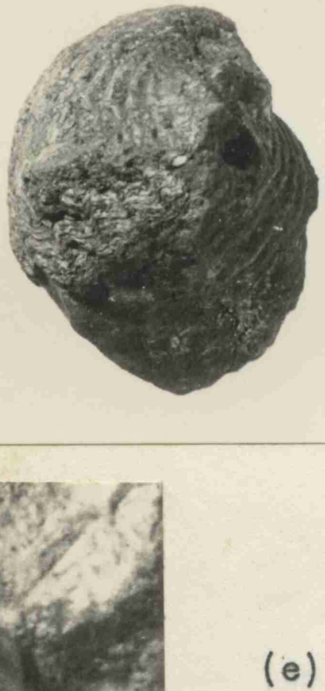


(b)



(c)

(d)



(e)

EXPLANATION OF PLATE 22.

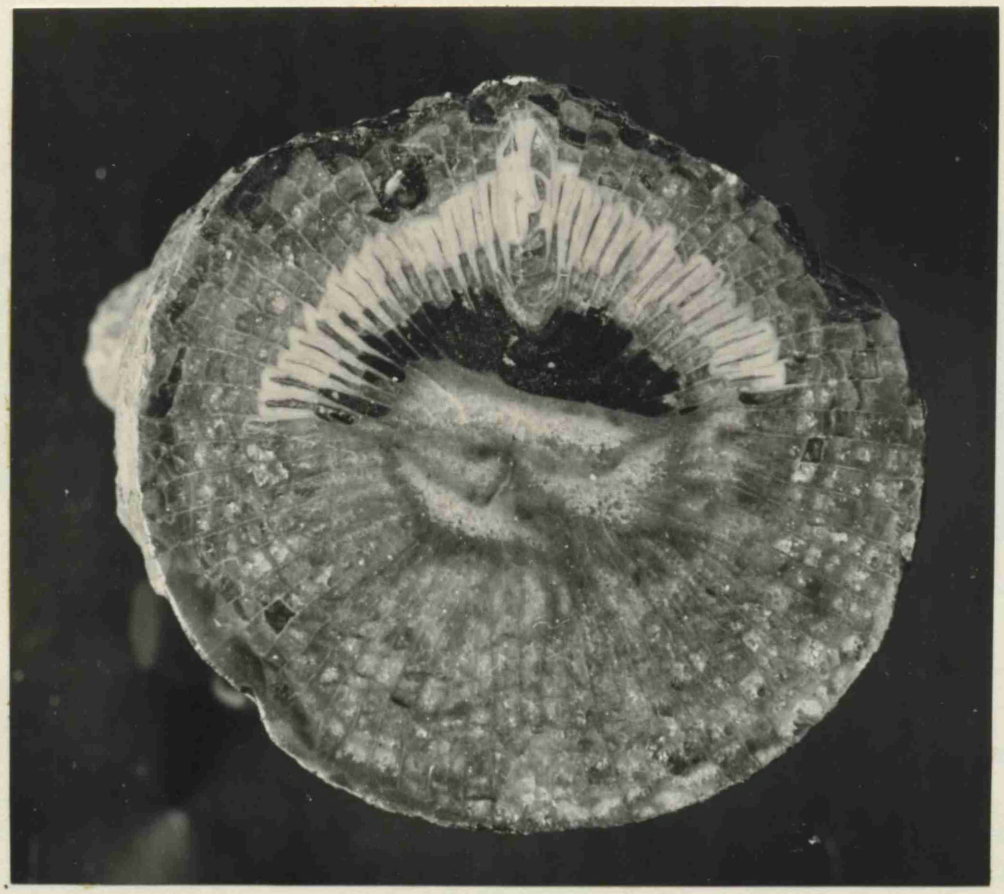
Tylothyris laminosa

(a) & (b) Dorsal views of two specimens, the first showing the narrow, triangular delthyrium.
(c) & (d) Lateral views of (a) and (b) respectively showing variation in the degree of incurvature of the ventral umbo. These specimensare from the same bed. X 1½.

Phillipsia cf. scabra

(e) View of the pygidium. X 6.

PLATE 23.



(a)

(b)

EXPLANATION OF PLATE 23.

Caninophyllum aff. patulum

(a) Transverse section of a specimen closely similar to those described and figured by Smyth (1930, pl.16, figs. 2 & 3) from Hook Head. X 2.
(b) Transverse section of a specimen showing particularly long septa. X 2.

PLATE 24.

(a) (b)

(c)

(d)

EXPLANATION OF PLATE 24.

Carruthersella sp.

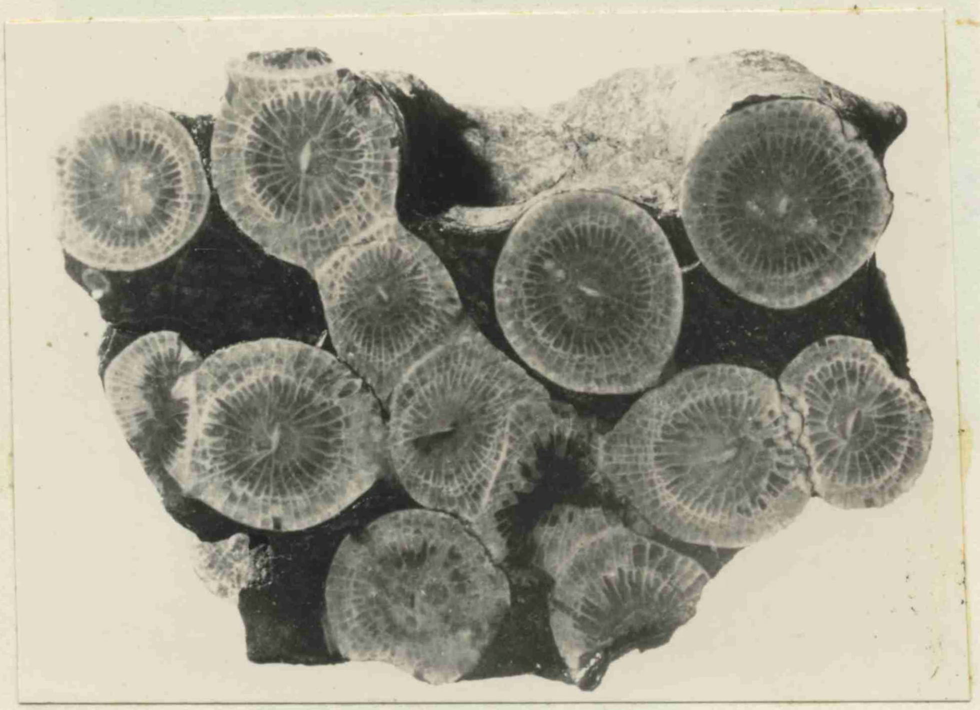
(a) & (b) Transverse sections of two specimens respectively at 5 mm. and 15 mm. below the calyx. X 2.

Cyathoclisia tabernaculum

(c) Transverse section showing particularly well the long clearly defined cardinal fossula and long, flexed major septa. X 2.
(d) Longitudinal section. X 2.

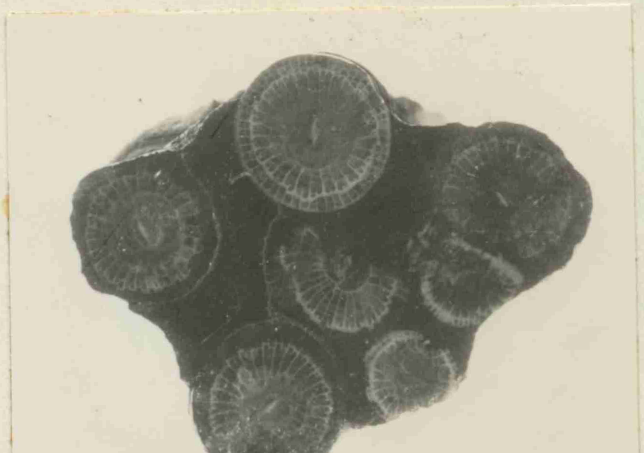
PLATE 25.

(a)



(c)

(b)



EXPLANATION OF PLATE 25.

Lithostrotion cf. *affine*

(a) Transverse section. X 2.

Lithostrotion cf. *scoticum*

(a) Transverse section showing the long major septa and the counter cardinal septum extending almost to the lenticular epitheca. X 2.
(b) Longitudinal section showing the arched tabulae. X 2.

PLATE 26.

(a)

(b)

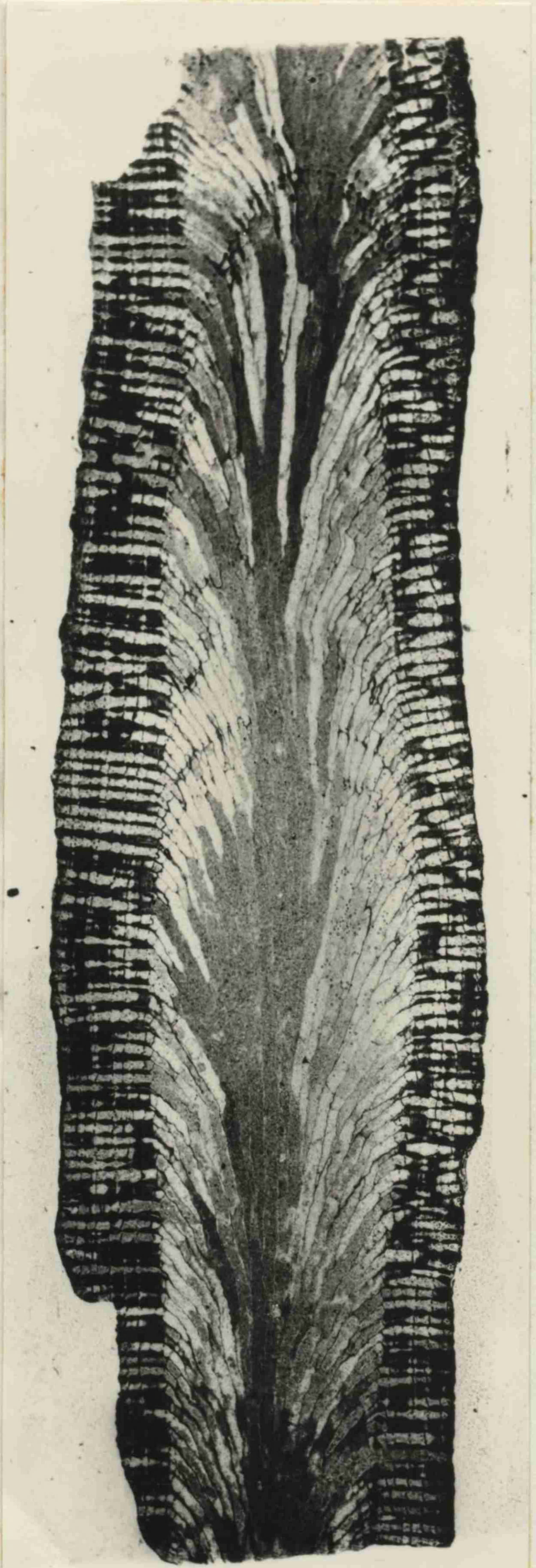
EXPLANATION OF PLATE 26.

Lithostrotion cf. martini

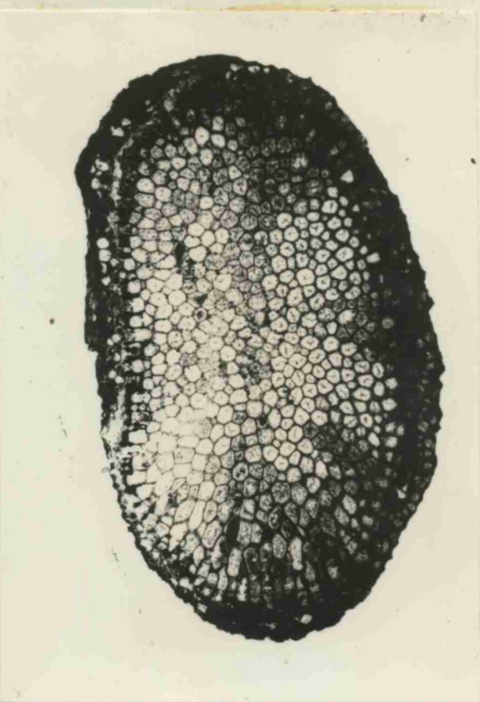
(a) Transverse section showing the long minor septa and prominent dissepimentarium. X 2.
(b) Longitudinal section showing the conical tabulae. X 2.

PLATE 27.

(b)



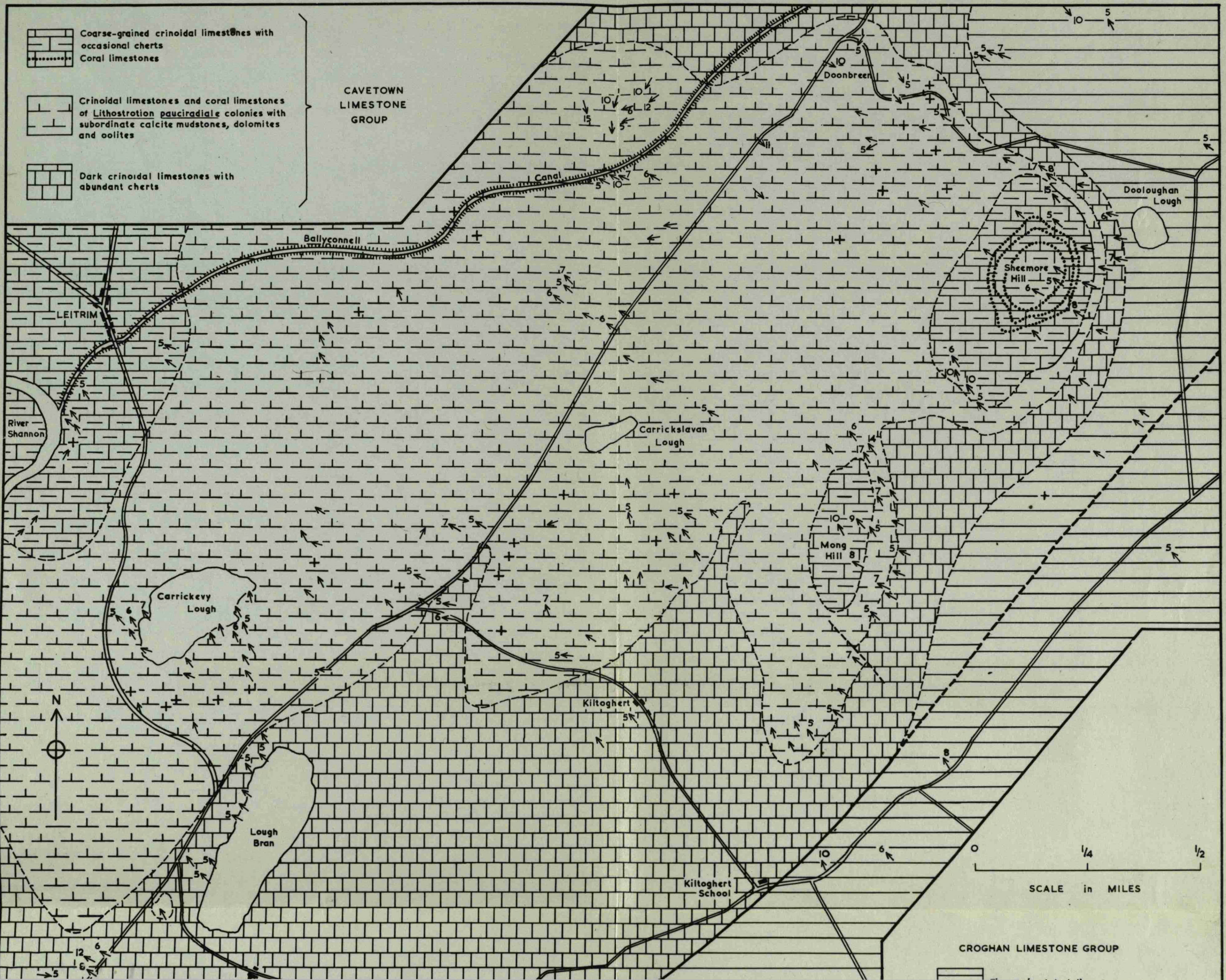
(a)



EXPLANATION OF PLATE 27.

Rhomboporella sp.

(a) Transverse section. X 6.
(b) Longitudinal section. X 6.


Coarse-grained crinoidal limestones with occasional cherts
Coral limestones
Crinoidal limestones and coral limestones of Lithostrotion pauciradiale colonies with subordinate calcite mudstones, dolomites and oolites
Dark crinoidal limestones with abundant cherts
CAVETOWN LIMESTONE GROUP
CROGHAN LIMESTONE GROUP
SCALE in MILES
0
1/4
1/2
N
LEITRIM
River Shannon
Ballyconnell
Canal
Doonbreen
Dooloughan Lough
Sheemore Hill
Carrickslavan Lough
Mong Hill
Carrickevy Lough
Lough Bran
Kiltoghert
Kiltoghert School

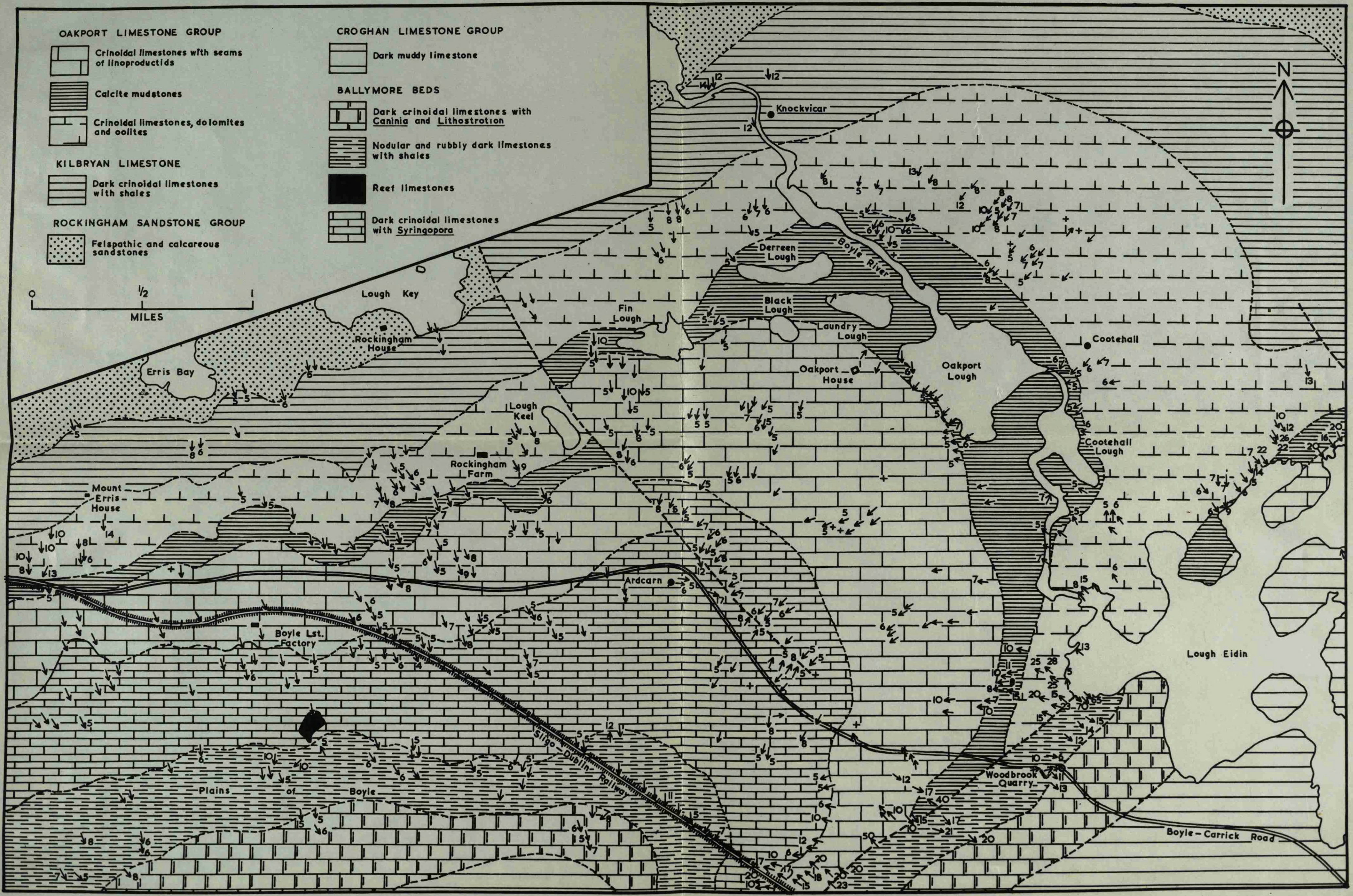


Fig. 4. Map of the solid geology of the Oakport - Rockingham district

GEOLOGICAL MAP OF THE CARRICK SYNCLINE

BY W.G.E. CALDWELL