LOWER CARBONIFEROUS LITHOSTRATIGRAPHY OF THE IRISH MIDLANDS

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Based on a symposium held at the

ATHLONE REGIONAL TECHNICAL COLLEGE on 11th June 1983

IRISH ASSOCIATION FOR ECONOMIC GEOLOGY

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Following the discovery of the 70mt+ carbonate-hosted Zn/Pb orebody at Navan by Tara Exploration and Development Co. Ltd. in 1970, an increasingly large amount of attention was devoted by the exploration industry to the potential of the Lower Carboniferous (Dinantian) sequence of the Midlands of Ireland. During the 1970's a considerable amount of diamond drilling was carried out in this area, which is singularly poorly exposed. A very large amount of valuable geological information was obtained during this period, most of which remained confidential to the exploration companies, as there was, at that time, no scheme whereby such data could be made accessible to other interested parties. Following a period in the early 1970's during which exploration companies carried out their prospecting in an atmosphere of relative secrecy, the late 1970's saw a more relaxed attitude to the release of such information, and an informal system of data exchange evolved. However, this exchange of information was generally on a one-to-one basis, and it was often quite difficult for a recently-arrived exploration company to obtain basic information, when they themselves had nothing to offer in return. It was in these circumstances that the Irish Association for Economic Geology, with the co-operation and support of the exploration industry, organised the first Midlands Correlation Symposium in 1976. This was followed in 1977 by the Munster Basin Correlation Symposium which focussed on the Lower Carboniferous succession further south. In 1979 the IAEG hosted the Institution of Mining and Metallurgy meeting "Prospecting in areas of Glaciated Terrain", which was held in Dublin, and in 1981 the Association organised the symposium "Mineral Exploration in Ireland: Progress and Developments 1971-1981", which was held in Wexford. Following these two major and very successful international meetings, and as a lot of work had been done in the Midlands since 1976, it was thought opportune to hold another Midlands Correlation meeting. However this time it was felt that something more substantial should emerge from the meeting.

On 11 June 1983 a one day symposium was held at the Regional Technical College in Athlone, with the co-operation of the RTC's Department of Mineral Science. On the previous evening Dr. G. Sevastopulo had set the scene for the meeting by giving a talk on the palaeogeography of the Dinantian of the Midlands. The symposium itself was divided into two parts; the first section comprised individual contributions on the lithostratigraphy of particular areas, and the second section consisted of a discussion period. Opening the latter session Dr. M. Philcox presented lithostratigraphical correlation charts for the region. These charts provided the basis of a wide-ranging discussion of both correlation and terminology, and were subsequently updated for this publication.

Neither the symposium nor the publication would have been possible without the goodwill and co-operation of the exploration and mining industry of Ireland. The IAEG is particularly grateful to all of the companies and individuals who have made this publication possible, and who are mentioned in the acknowledgements at the end of the volume. We also extend our appreciation to Prof. Peter Bruck, University College Cork and to Dr. George Sevastopulo, Trinity College Dublin, who acted as Chairmen for the meeting. Our thanks go also to Ken Chew of Petroconsultants Ltd. who arranged for the drafting of the correlation charts. Three members of the IAEG Council were specifically charged with organizing the symposium and seeing the publication through: Bill Pennell, Christian Schaffalitzky and Ed Slowey, by their persistent detective work, located the cores that were crucial to the success of the symposium. A very special word of thanks is due to Ed Slowey who, almost singlehandedly, saw through the production of the correlation charts and the accompanying text.

This volume, however, is really a testimony to the work of one man - Dr. Michael Philcox. During the weeks immediately preceding the meeting Mike Philcox examined the drillcore which formed the basis of the individual presentations at the meeting. He then drew up the preliminary correlation charts which were presented at the symposium. Afterwards Mike examined further cores and produced the correlation charts which form the kernel of this publication. Finally, he has written a text which provides detailed lithostratigraphical descriptions and also discusses correlations.

The IAEG gratefully acknowledges the assistance given to Dr. Philcox through the Upper Palaeozoic Atlas of Ireland (UPAIR) project, a project which is funded in Trinity College Dublin by the Department of Energy, and supervised by the Geology Department at T.C.D. and by the Geological Survey.

Ireland has an enviable mineral potential; this has been adequately demonstrated by the discovery of the major deposits at Navan, Silvermines, Ballynoe, Avoca, Tynagh and Gortdrum. However orebodies are becoming progressively more difficult to locate and it is only by making the maximum use of the available knowledge that further discoveries will be made. The IAEG hopes that this publication will help towards a basic understanding of the geology of the Irish Midlands and may assist in the discovery of further mineral deposits.

John Pyne
President(1983)
Irish Association for Economic Geology

1. Introduction

1.1 Background and Intent

A large amount of new stratigraphic material has become available with the release of cores for the I.A.E.G. Symposium in Athlone in June 1983. Successions, mainly Tournaisian, at some twenty localities in the Irish Midlands are represented (fig. 1). As the area is generally poorly exposed, and few drilled successions have previously been published, this offers an opportunity for a major advance in the study of the Irish Carboniferous.

Previously published work on the area includes summaries of the general stratigraphic setting by MacDermot and Sevastopulo (1972), Naylor and Sevastopulo (1980), Sevastopulo (1981); regional biozonation by Clayton and Higgs (1979), Sevastopulo (1979), Clayton et al. (1980); and brief accounts of successions around the mineral deposits at Silvermines (Rhoden, 1958; Taylor and Andrew, 1978; Bruck, 1982; Taylor, 1984), Tynagh (Derry et al., 1965; Schulz, 1966), Ballinalack (Jones and Bradfer, 1982) and Navan (Andrew and Ashton, 1982). Extensive (unpublished) mining company work has been largely unco-ordinated, leading to a multiplicity of informal stratigraphic terms, and generally limited understanding of regional correlation. Some restricted areas and parts of the succession have been studied in more detail for unpublished theses.

The purposes of this paper are to outline the lithological successions in the recently released cores, to correlate them where possible on the basis of lithologies, and to unify the stratigraphic nomenclature at an informal level. The paper is intended primarily as a practical reference work for geologists interested in the Irish Carboniferous. The reader wanting only an introduction to the stratigraphy is referred to the outline on pp 8-10 or the longer summary on pp 67-73.

1.2 Organization of this Paper

Because the succession is different in each of four stratigraphic provinces, and because inter-province correlations are uncertain, the detailed stratigraphy of the Symposium area is described below province by province. A discussion of inter-province correlations is then followed by a summary of the overall stratigraphy and some of its implications. It is impracticable to describe each borehole succession, but details of some of them can be pieced together by reference to hole numbers and depths given in successive sections of the text, using the index and columnar sections as a guide.

1.3 Compilation of the Cross-Sections

Most of the cores have been graphically logged by the author on a scale of 1":50ft or 1":10m, according to the labelling of the core boxes. A few cores were logged in outline only, as specified in the text. The 1:2500 columnar sections (figs. 2-4) are simplified summaries. Some artificiality is introduced by the symbols, since barely different lithologies can fall into separate categories. Grain sizes of sandstones, etc., have not been measured; quoted sizes ("coarse", etc.) are relative.

The columns have been corrected for dips of over 10°, to show true stratigraphic thicknesses. Down-hole depths are given (in feet or metres) alongside each column, to aid reference. It should be noted that in dip-corrected columns the down-hole depths are out of scale. In the text and tables all unit thicknesses are true stratigraphic thicknesses. Where individual columns are based on more than one core, the down-hole depths of boundaries judged common to each are shown on opposite sides of the column. Gaps have been left where significant slices of section appear to have been faulted out or have not been drilled. A "lightning" sign shows the position of less significant faults. The lines of section have been chosen to show the correlations most clearly.

The Navan column in figure 3 is a compilation derived from Tara Mines' and Selection Trust's cores, drilled 1-2 miles (1.6-3.2 km) apart, based on the author's detailed work for Tara Mines since 1971 (summarized in an unpublished report, March 1980). In the mine area at Navan the succession surviving below the Visean unconformity extends up to the bottom of the Shaly Pale Beds (Andrew and Ashton, 1982, fig. 2); in fault slices most of the Shaly Pale Beds are also represented. A mile or two west and north-west of the mine a much fuller succession survives. Selection Trust cores, drilled in the early 1970s, provided a nearly complete succession up to the reef top and lowest overlying beds. Faulting and lack of markers obscured the true thickness of the Crinoidal Limestone Unit. The Selection Trust cores have since been destroyed.

The Wheatfield column (fig. 4) is a simplified version of a composite section prepared from a least seven cores by Drs. Strogen and Somerville (University College, Dublin), who kindly supplied the data summarized on p 62. A more detailed account is in preparation by them.

1.4 Stratigraphic Provinces

1.4.a General--- The distribution of cores released for, or previous to, the I.A.E.G. Symposium is shown on the map (fig. 1), and defines what is referred to below as "the Symposium area". Among the cores the successions hosting the mineral deposits at Navan, Ballinalack, Keel, Tynagh and Silvermines are included. The stratigraphic range of the successions reflects the main host-rock targets in recent mineral exploration: the principally Tournaisian Waulsortian reef and underlying limestones. (The Visean host limestones of the Kildare deposits are excluded; see Holdstock, 1982.) Younger beds in areas where the Waulsortian is absent are also discussed here. Most cores terminated in the top of the basal clastics (Old Red Sandstone); a few, mainly in the north, reached the unconformity at the top of the Lower Palaeozoics.

All the successions represent transgressive sequences, or parts of them, from terrestrial red beds, up through various marginal marine sediments, into fully marine limestone and shales, most culminating in deep-water Waulsortian reefs (mudbanks). There is, however, considerable variation. Four basic types of sub-reef successions can be recognized, each related to a distinct geographical area; i.e. four lithostratigraphic provinces are represented. Within each there is smaller-scale variation, while some transition and intertonguing between provinces is apparent in marginal areas. There are thus "typical" and "marginal" successions within each province. The distinguishing features of the provinces, and the location of representative successions, are shown in Table 1.

The approximate distribution of the provinces is shown in figure 6; the boundaries between them are as yet poorly established. The North Midlands Province occupies most of the northern part of the Symposium area, and is contiguous with the Dunmore and Limerick Provinces. It may extend westwards between these two. Its southern boundary is likely to be separated from the Kildare Province by one or more distinct successions in the Dublin Basin, including that in the Trim No.1 well (fig. 1), outlined by Sheridan (1972). The Limerick Province lies mainly south-west of the Symposium area, but the Silvermines and Tynagh successions are typical. Other Symposium cores in this province show marginal successions. The Dunmore and Kildare Provinces are poorly represented and their limits very uncertain in most directions. The lithostratigraphic provinces do not necessarily coincide with structurally controlled depositional basins, which can be smaller or larger than the provinces (See Section 8.2).

Typical successions in the four provinces are outlined in Table 2. Unit names applied here are as far as possible those now in most common use, with some additions and adaptations to provide uniformity. No attempt is made to formally define and name units. Lithostratigraphic correlation between provinces depends largely on identifiable units crossing province boundaries at least into marginal areas. Few of the presently released cores reveal critical relationships, so there is considerable uncertainty as to the lateral equivalence of some of the major units. Interpreted relationships are shown in diagrammatic form in figure 5 and summarized below. Detailed evidence is given in the main text. Correlations are limited to some extent by a lack of detailed biozonation and by the continued confidentiality of cores from some key transitional areas.

Table 1: Identifying Characteristics of the Stratigraphic Provinces

Province Name	Typical Succession	Characteristics[1]
North Midlands Province (N.M.P.)	Ballinalack	Widely varying basal successions overlain by Micrite Unit and younger Pale Beds, followed by Upper Sst and Shaly Pale Beds. Younger beds (A.B.L.) not diagnostic.
Dunmore Province	Dunmore	Basal Sst overlain by thin transitional sequence, then very condensed A.B.L. relative to N.M.P. No distinct Pale Beds or Shaly Pale Beds.
Limerick Province (L.P.)	Silvermines[2]	O.R.S. with Basal Sst at top, overlain by transitional M.H.B., then calcareous (Ringmoylan) shales and thin green Ballyvergin Shale marker, followed directly by thick argillaceous limestone succession (Ballysteen Lst.) mainly similar to A.B.L. No Pale Beds, Upper Sst. or Shaly Pale Beds.
Kildare Province	Boston Hill	Succession reminiscent of N.M.P. and L.P., but no Pale Beds except Micrite Unit, no Upper Sst or Shaly Pale Beds. Includes distinctive laminated silty limestone beds scattered in middle, and thick crinoidal dolomite in upper part.

(1) Unit abbreviations as in key to cross-sections
(2) Representative within Symposium area, but "type" succession is in north Co. Limerick (different in detail only).

TABLE 2

SUMMARY OF TYPICAL LITHOLOGICAL SUCCESSIONS IN THE FOUR PROVINCES

KILDARE PROVINCE	LIMERICK PROVINCE (L.P.)	NORTH MIDLANDS PROVINCE (N.M.P.)	DUNMORE PROVINCE
Waulsortian Reef:Composition mainly as in L.P. Isolated reefs.Absent in Boston Hill core.	Waulsortian Reef:Pale grey biomicrite rich in fenestrate bryozoa, with internal sediment, fibrous calcite("stromatactis")	Waulsortian Reef:Composition as in L.P.. Absent in northern areas.	Waulsortian Reef:Composition as in L.P. Mainly small and isolated.
Upper Dolomite:mainly coarse,dolomitized crinoidal calcarenite. Calcarenite A:fine argill. calcarenite with minor chert.	Upper Ballysteen Lst:argill.lsts. & shales,better differentiated than Middle Ballysteen, shalier.	Argill.Bioclastic Lst:Argill.lst. and shales,becoming increasingly shaly upwards.Mainly similar to Upr.Ballysteen (L.P.)	Argill.Bioclastic Lst: as in N.M.P.,but much thinner;fewer sub-units.
Shaly Units:thinly interbedded shales & lsts,some burrowed silsts. Three main units recognised (Fig.4) Calcarenite B:fine calcarenite with shale partings. Upper Laminated Lst:varied lsts. with distinctive beds of lam.,burrowed silty lst. Main Bioclastic Lst:relatively uniform argill.lst; minor shale. Lower Laminated Lst:as Upper Lam. Lst. Oolite Unit:mixed calcarenites including common oolite beds. Calcarenite C:mixed calcarenites, some argillaceous. Micrite Unit: Argill.micrite, subordinate shale.	Middle Ballysteen Lst:argill.lst. with very subordinate shale. Top gradational. Relatively uniform.	Shaly Pale Beds:mixed unit of burrowed silty lsts.,thick unfoss. shales,biosparites,ssts.,etc.Rich bryozoan fauna locally. Three distinct "members" at Navan. Upper Sst:Pale grey calc.sst. with minor lst.interbeds. Absent in south. Pale Beds:Mixed sandy lsts., oolites,micrites,ssts,minor shale. Thick Micrite Unit ("member") at base. Micrite Unit	Un-named transitional sequence: ssts.,siltsts.,& shales, probably representing Shaly Pale Beds,Upper Sst. and upper part of Pale Beds. Basal Sst:composition as in L.P. Possibly laterally equivalent in upper part to Pale Beds and lower units in in N.M.P. and lower part of of Middle Ballysteen in L.P. (Red Beds not penetrated).
Calcarenite D:mixed calcarenites with minor shale.	Lower Ballysteen Lst:thinly nodular bedded lst. and shale. Well defined top and bottom.	Basal Transition Beds: Mixed, laterally varied sequences, locally absent. "lst facies" at top in south:argill.lst. & minor shale. "shaly facies" more widespread: dominantly heterolithic shale/ sst., with thicker ssts.,siltsts., silty lsts & shale; probably partly equivalent to Basal Sst.	
Lower Lst.Shales:mainly thin-bedded shales and sst., with lsts. in upper part.	Ballyvergin Shales:green grey non-calc. silty shale marker bed. Ringmoylan Shales:foss. shale and subordinate thin lst.beds. Mellon House Beds:mixed fine calc. ssts.,burrowed siltsts,shales, rare lsts.		
Red Beds:red siltst.,sst. and minor conglomerate.	Old Red Sandstones a)Basal Sst:thick-bedded,pale grey,coarse-medium sst., relatively uniform. b)Red Beds:mixed red and pale grey units,dominantly siltst., with sst., conglomerates and and mudstones.	Old Red Sandstone: upper unit. Basal Sst:composition as in L.P. Present in west and centre; Absent in east. ORS, lower unit: Red Beds:mainly thin, discontinuous red beds; thicker in south.	

Abbreviations

lst.	=	limestone
siltst.	=	siltstone
sst.	=	sandstone
argill.	=	argillaceous
lam.	=	laminated
foss.	=	fossiliferous
calc.	=	calcareous

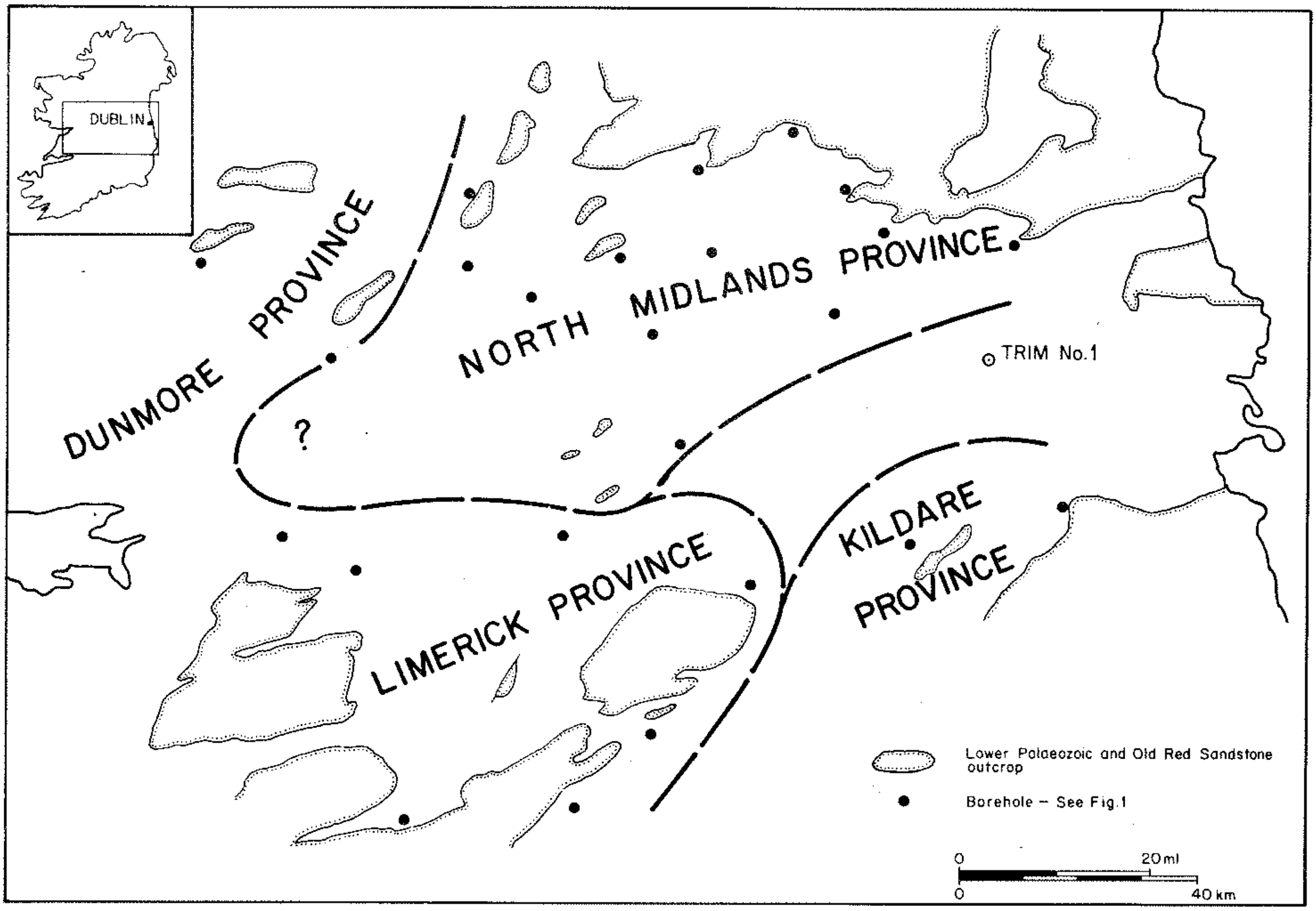

FIG. 6. TENTATIVE BOUNDARIES OF STRATIGRAPHIC PROVINCES.

1.4.b Limerick Province.--- Thick, varied Old Red Sandstone sequences are subdivided into Red Beds and Basal Sandstone, the latter a widespread unit of coarse, pale sandstone. This is overlain by a transitional sequence, the Mellon House Beds, of finer sandstone, burrowed siltstone and mudstone, with a sharp top. The unit passes out northwards, apparently into Basal Sandstone. Ringmoylan Shales, calcareous shale with thin limestones, commonly with haematitic grains at the base, overlies the two lower units. The top contact is defined by the base of the Ballyvergin Shale in the south, but the facies extends up into younger beds northwards. Where the Ballyvergin loses its identity towards Cloghan, the whole shale sequence becomes the "Ferbane Mudstone". North of the Moate Inlier (fig.1) this unit apparently pinches out within the diachronous Basal Sandstone. The Ballyvergin Shale is a unique, synchronous marker that crosses various facies belts from south to north within the Limerick Province. It is overlain by a thick succession of varied argillaceous limestone and shale, the Ballysteen Limestone. The Lower Ballysteen can be clearly separated and has a well defined, probably synchronous top. North-eastwards the upper part of the Lower Ballysteen is replaced by the Cloghan Sandstone, which is a major tongue extending from the North Midlands Province. The Middle/Upper Ballysteen boundary is gradational. Between the two in the Borris-Templemore area is intercalated a sequence of oolite and cherty, silty limestone of non-Ballysteen facies. Typical Waulsortian reef limestone overlies the Ballysteen.

1.4.c North Midlands Province.--- Red Beds are thin or absent, except in the south. Basal Sandstone forms the dominant part of the Old Red Sandstone in central and western areas. The upper part of this is apparently much younger than in the Limerick Province, and extends far to the south as the Cloghan Sandstone. In eastern areas Lower Palaeozoics or Red Beds are overlain directly by Basal Transition Beds, complex sequences dominated by heterolithic shale and sandstone, with thicker sandstone beds and subordinate limestone (together, the "shaly facies"). The thicker sandstones possibly represent tongues of Basal Sandstone, comparable with the Cloghan Sandstone. Basal Transition Beds overlie Basal Sandstone in central and western areas, except in an axial zone through Keel, where Basal Sandstone is directly overlain by Pale Beds. In southern holes the upper part of the Basal Transition Beds consists of argillaceous limestone units ("limestone facies"), the culmination of an initial transgressive phase. They may be equivalent to the Lower Ballysteen Limestone.

A widespread Micrite Unit, basal member of the Pale Beds, crosses Basal Sandstone, Cloghan Sandstone, and both shaly and limestone facies of the Basal Transition Beds. The overlying Pale Beds consist mainly of sandy limestone, sandstone, oolite and further micrite beds in a "transitional" sequence entirely different from the Basal Transition Beds or Mellon House Beds. An extensive, thick sandstone, the Upper Sandstone, covers the Pale Beds, except in the south. The overlying Shaly Pale Beds are dominated by silty burrowed limestone and thick, unfossiliferous shale beds. The Pale Beds/Shaly Pale Beds interval apparently passes south-west into the Middle Ballysteen. Critical evidence for this correlation is provided by the Cloghan borehole, where typical Middle Ballysteen Limestone overlies Cloghan Sandstone, which further north is overlain by the Micrite Unit. Argillaceous limestone and shale, the Argillaceous Bioclastic Limestone (A.B.L.), is very similar to the Upper Ballysteen; it overlies the Shaly Pale Beds and underlies Waulsortian reefs. Where Waulsortian is absent, A.B.L. extends up into the Visean (probably the lower part of the Chadian only), and is variously overlain by radically differing younger Visean sequences. Within the North Midlands Province the successions are condensed by up to 50% in "northern" holes, where the Waulstortian is generally missing.

1.4.d Dunmore Province.--- Thick Basal Sandstone is overlain by a thin transitional sequence, which appears to include the Upper Sandstone-Shaly Pale Beds interval of the North Midland Province. This is overlain by condensed Argillaceous Bioclastic Limestone and isolated reefs. It is not known whether the Basal Sandstone here is laterally equivalent to either Pale Beds or Lower Ballysteen Limestone.

1.4.e <u>Kildare Province</u>.--- An initial transgressive sequence is comparable with that in the North Midlands Province: Red Beds are overlain by thin-bedded sandstone and shale (Lower Limestone Shales) with limestone in the upper part. An overlying Micrite Unit extends the comparison with the North Midlands Province, but above that a varied succession of clean and argillaceous limestones is unlike those in other provinces. Some units include distinctive finely laminated silty limestone, similar to that between the Middle and Upper Ballysteen Limestone in the Templemore-Borris area. Shalier units, possibly equivalent to the Shaly Pale Beds and A.B.L., overlie these limestones. These in turn are overlain by coarse, mainly dolomitized calcarenite, which has no counterpart in the other provinces, and may possibly be laterally equivalent in the upper part to Waulsortian reefs. The Boston Hill succession thins eastwards towards the Leinster Massif, as shown by the Wheatfield succession.

2. North Midlands Province

2.1 Introduction

The principal distinguishing feature of the North Midlands Province is the presence of the Pale Beds to Shaly Pale Beds succession, within which the Micrite Unit and, except in the south, the Upper Sandstone are particularly prominent units. The typical succession is outlined in Table 2. Some units, notably the Argillaceous Bioclastic Limestone, are not restricted to this province. Approximate boundaries of the province are shown in figure 6. Within the province there are distinct differences in thickness and composition between successions in a northern arc from Crossakeel to Newtown Cashel, and those in the centre and south. For convenience these groups are referred to as "northern" (holes in figure 2, except Keel) and "southern" (holes in figure 3, except Crossakeel). The Windmill Hill succession, which is probably marginal to the province, is incomplete and difficult to correlate; it is discussed separately below. Apart from that, the main units in the province are described below in chronological order.

2.2 Old Red Sandstone

2.2.a Divisions.--- Old Red Sandstone in the North Midlands Province ranges in thickness from over 135 ft (41 m) at Sion Hill to zero in some northern holes; its composition is equally varied. Two main units are recognized: Red Beds and overlying pale grey Basal Sandstone. The distinction is sharp in most cores, but in the most northerly ones the Basal Sandstone can be weakly coloured red and green. Either or both units are absent in some holes.

2.2.b Red Beds.--- In most Symposium holes in the North Midlands Province, Red Beds occur as relatively thin (up to 20 ft, 6 m) lenticular units of red fine-grained sediments unconformably overlying the Lower Palaeozoics. In several drilling areas, notably Keel, Granard and Oldcastle, they are present in some holes but not in others, which suggests deposition on an irregular surface. They are absent in the Lough Sheelin (LS-14) and Crossakeel holes (CK-2) and have not been reported from Ballinalack (Jones and Bradfer, 1982). At Navan the Red Beds unit is at least 50 ft (15 m) thick in some holes, but absent in others. Here it is dominated by coarse red conglomerate, including locally derived igneous clasts over 2 in (5 cm) across, but red siltstone beds are also present. Topography on the unconformity surface at Navan was evidently less mature, in spite of the southerly location.

At Sion Hill the Red Beds are much thicker and include both red and green units. SH-4 penetrated 135 ft (41 m)(620-763 ft) without reaching the unconformity:

(620 ft)	Base of black shales.
18 ft(5.4 m)(620-639 ft)	Very pale green mudstone with probable caliche carbonate; very disturbed, locally brecciated, by caliche formation. Slabs of green mudstone form a sedimentary breccia at the base of the overlying black shale.
34 ft(10.3 m)(639-676 ft)	Green sandstones of varied grain size, mainly coarse and well banded with micaceous partings and locally with green mud flakes; pebbly sandstone below 653 ft with scattered quartz pebbles up to 3/4 in (2 cm) across.
1 ft(30 cm)(676-677 ft)	Isolated red siltstone.
c.25 ft(7.7 m)(677-704 ft)	Pale blue-green mudstone, locally with coarse sandstone, churned up apparently during caliche formation.
c.60 ft(18 m)(704-763 ft,TD)	"Red mudstones, sandier towards the bottom" recorded by Riofinex below 704 ft. Only the top 6 ft of core was available for this study: bright red mudstone and siltstone with 2-mm carbonate nodules.

In the Strokestown core red and green mudstone and sandstone occur in several units up to the top of the Pale Beds. These coloured beds are quite separate from the Red Beds unit to the south; they are interpreted as part of the lateral passage of units at higher stratigraphic levels into their terrestrial equivalents further north. The Red Beds unit was not reached in BB.82-4.

The available data from the Symposium holes indicates that the Red Beds in the North Midlands Province thin from over 135 ft (41 m) at Sion Hill to less than 20 ft (6 m) further north and west, commonly pinching out altogether. Anomalously coarse (alluvial fan?) sediments and high palaeo-relief at Navan indicate that facies belts are not simply distributed.

2.2.c Basal Sandstone.--- In the central part of the North Midlands Province (Keel, Granard, Ballinalack and probably Newtown Cashel) the Lower Palaeozoics and pockets of Red Beds are sharply overlain by thick sections of Basal Sandstone (185 ft, 56 m known). The unit consists of pale yellow-grey sandstone, mainly medium- to coarse-grained and non-calcareous. Subordinate interbeds up to 5 ft (1.5 m) thick of both light green-grey and dark grey mudstone can be present; and rarely also burrowed dark silty sandstone.

At Keel the Basal Sandstone (185 ft, 56 m thick) includes a 35-ft (11-m) basal unit (KA-158, 1377-1417 ft) of coarse conglomerate with minor sandstone interbeds. The conglomerate extends northwards into the Longford-Drumlish area, where it outcrops. Rounded cobbles up to 7 in (20 cm) across consist of grey, green and sometimes red quartzite with subordinate vein quartz. In other holes sandstone with scattered pebbles is often present near the bottom of the Basal Sandstone, but rarely conglomerate.

At Moyvore similar sandstones were penetrated, both immediately below the Micrite Unit and in fault slices, which are interpreted by Amax geologists to be 200-300 ft (60-90 m) lower. As this fault gap leaves room for a possible wedge of Ferbane Mudstone (see fig. 3), it is not certain whether beds immediately below the micrite should be referred to the Basal Sandstone or the Cloghan Sandstone.

At Strokestown a thick section of homogeneous pale sandstone, interpreted as the Basal Sandstone unit, is exposed near the BB.82-4 drill site, but was not penetrated in the hole. At Granard the Basal Sandstone is only 30 ft (9 m) thick in GR-5, and is exceptional in being weakly red and green coloured. The top 13 ft (4 m) includes common bands of cream micrite. It is overlain in GR-5 by a fine sandy conglomerate 6 ft (2 m) thick with some micrite clasts, suggesting an erosion surface just below the Micrite Unit. However, in GR-20 the contact with the Micrite Unit is gradational.

2.2.d Lateral Relationships of the Basal Sandstone.--- Lateral relationships of the Basal Sandstone are complex. The upper part of the unit, if not the whole of it, appears to pass south as a major tongue, the Cloghan Sandstone, above the Ferbane Mudstone (figs. 3 & 5), since both are overlain by the Micrite Unit (p.65). The Ferbane Mudstone pinches out northwards, apparently either into the Basal Sandstone (as in fig. 5), or below it. The latter is less likely, because at least as far north as the Moate Inlier the Ferbane Mudstone is underlain by Basal Sandstone. The Basal Sandstone in the Keel (and possibly Moyvore) area is thus interpreted as a composite unit, the upper part being much younger than the top of the Basal Sandstone at Moate and further south.

In the eastern part of the North Midlands Province (east of Granard/Ballinalack) none of the Symposium holes have Basal Sandstone as an identifiable unit immediately above the unconformity or Red Beds. However, several of these holes include within the Basal Transition Beds one or more relatively thick sandstone units (e.g. 40 ft, 12 m, at Sion Hill), which are similar to the Basal Sandstone. It is possible that these are tongues, comparable with the Cloghan Sandstone, extending from the upper part of the Basal Sandstone further west.

Intertonguing or direct lateral passage between the lower part of the Basal Sandstone and Red Beds at Sion Hill cannot yet be ruled out either. The general character of the 34-ft (10.3 m) green sandstone in SH-4 (639-676 ft, see above) is similar to the Basal Sandstone except for colour; both are pebbly in the lower part. Lateral equivalence would imply down-slope facies change towards the west or north-west, rather than south as expected from the overall pattern. It is not inconsistent on present evidence to suggest possible extensions from the Basal Sandstone into both Red Beds and Basal Transition Beds, because of the inferred composite nature of the Basal Sandstone in the central part of the North Midlands Province. However, more work is required to resolve these relationships.

The thickness of the Basal Transition Beds overlying the Basal Sandstone varies, apparently systematically. The Basal Sandstone at Keel is directly overlain (in LF-16 and KA-158) by Pale Beds. At Newtown Cashel and Granard Basal Transition Beds are at most only a few feet thick, while further east and west they become thicker (Ballinalack 30 ft, 9 m; Sion Hill c.380 ft, 116 m; Strokestown over 200 ft, 60 m). This suggests a drape-like relationship with the underlying Basal Sandstone on a broad scale, the sandstone forming a central north-south lobe in the Keel area (parallelling the basal conglomerate). Known thicknesses of Basal Sandstone accord with this, though data is limited on the west side. Southwards this thickened lobe evidently extends as the Cloghan Sandstone.

If this interpretation of the lateral relationships of the Basal Sandstone is correct, it implies that the top of the Old Red Sandstone (currently placed at the top of the Basal Sandstone) interfingers with other units on a surprisingly large scale within the Symposium area; specifically with units as young as the Lower Ballysteen Limestone (see below, p.47). Structure-contour and isopach maps based on this surface should be interpreted with appropriate caution.

2.3 Basal Transition Beds

2.3.a Introduction.--- This term is applied here to all units in the North Midlands Province between the base of the Micrite Unit and the Old Red Sandstone or, where this is absent, the unconformity. There is great variation in the successions, and lateral relationships are often unclear. In some areas Basal Transition Beds are absent, while at the other extreme a whole transgressive cycle, culminating in marine limestone, is present. Two main facies groups are distinguished. Most sections consist of varied shale, siltstone, sandstone and minor limestone, which constitute the "shaly facies". In southern holes this is overlain by varied argillaceous limestone and thin shale beds, the "limestone facies".

2.3.b Basal Transition Beds in Eastern Holes.--- The Basal Transition Beds successions in the eastern part of the North Midlands Province are shown in figures 2 & 3. The upper part of the Sion Hill succession was not fully established. Dolomitization has obscured original textures above 300 ft in SH.4, and the base of the Micrite Unit was not identified. SH-35 shows the top contact clearly, but underlying beds do not correlate with those in SH-4 below 300 ft. The two sections may nevertheless overlap, rather than be superimposed as shown in figure 3. The total thickness is in any case much greater than in the other holes and probably reflects its southerly basinward location. Thicknesses decrease northwards and are accompanied by facies changes.

The bottom contact of the Basal Transition Beds is sharp in all holes and accompanied by a thin conglomerate or breccia, except at Lough Sheelin. At Navan the conglomerate varies from 0-5 ft (~1.5 m) thick, is fine-grained and usually dark green. At Crossakeel and Lough Sheelin the base rests on Lower Palaeozoics; elsewhere on the Red Beds unit.

The top contact is variable, commonly with thin micrite beds for 5-10 ft (1.5-3 m) below a sharp contact at the base of a thick micrite sequence (e.g. SH-35, LS-59). Thin micrite conglomerates may also underlie the main micrite. At Navan transitional very argillaceous micrite rich in large oncholites is present locally in units up to 10 ft (3 m) thick.

In spite of the variation in thickness, a general correlation between these eastern successions is possible. In all the holes the lower part consists of a thick shaly heterolithic unit, which in the two southern holes is markedly shale-dominant towards the bottom. A sandstone overlies this in all holes, ranging in thickness from 76 ft (23 m) at Sion Hill (base 543 ft in SH-4) to 2-3 ft (1 m) in the three northern holes. Above this sandstone the succession gradually becomes more calcareous, though there is only limited continuity of units between holes. The upper part of the three southern holes is dominated by limestones (the limestone facies), while at Oldcastle thin limestone beds are present in the top few feet only. The correlations, though crude above the sandstone, suggest condensing of the successions northwards and eastwards from Sion Hill, though relatively minor lateral passage of the highest beds into the Micrite Unit northwards is also possible.

Lateral facies changes include a northward progression in the heterolithic shaly units below the sandstone from calcareous, variably sandy and burrowed units, locally with thin shell bands at Sion Hill and Navan, to strongly mud-dominant laminated units at Crossakeel and Oldcastle, and finally dark green gritty shales at Lough Sheelin. Similar green shales overlie the sandstone at Lough Sheelin, and a few ?-gypsum nodules are present higher up, features not present to the south. The top limestones give way towards Lough

Sheelin to calcareous shale with minor skeletal debris. The two southern holes include limestone units in mid section below the limestone facies; northwards these are replaced by weakly skeletal shales. Sandstone units become thinner and fewer east and north from Sion Hill --- a pattern compatible with the suggestion above (p.13) that at least some may be tongues extended from the Basal Sandstone to the west. The thinning and general facies changes in these Basal Transition Beds successions apparently reflect a northward approach to a shoreline, but not one supplying significant sand.

2.3.c Basal Transition Beds in the Central Area.--- In the central group of holes Basal Transition Beds are thin or absent above Basal Sandstone. The thickest section is at Ballinalack (B-84), 32 ft (9.7 m). Here shale-dominant heterolithic beds with uncommon bands of argillaceous micrite are overlain at the top by a 3 ft (1 m) calcareous sandstone with a faulted top contact. The fault appears to be small. Similar beds at Moyvore are only 6 ft (1.8 m) thick, with a sharp top and gradational base. At Newtown Cashel (L.18) similar beds are c.19 ft (5.8 m) thick, with gradational top. The unit is absent in the Keel and Granard holes. The Basal Transition Beds appear to be thinning out across the top of, and possibly into, a thick lobe of Basal Sandstone in the central area (p.14, above).

2.3.d Basal Transition Beds in the North-West.--- At Strokestown the Basal Transition Beds are considerably thicker than in holes further east, and there is a more gradational upward passage into the Micrite Unit. Three main units are recognized (fig. 2). A sandstone-dominant section over 100 ft (30 m) thick (BB.82-4, 1102 ft to bottom) was penetrated at the base of the hole. In contrast to the relatively homogeneous Basal Sandstone (exposed nearby at outcrop), this sequence consists of various sandstone types, some burrowed, in units up to 15 ft (4.6 m) thick, interbedded with silty mudstone, laminated shale/sandstone and rare thin micrite beds. Above 1102 ft is a thick shaly sequence (83 ft, 25.3 m, top at 1016 ft), dominated by greenish and reddish calcareous mudstone, and including scattered gypsum beds up to 1 ft (30 cm) thick, a few very argillaceous micrite beds with ostracods and some crinkly lamination (stromatolites?), and minor cross-bedded, sometimes pink sandstones. These beds are overlain by a 50 ft (15 m) sequence (965-1016 ft) of varied lithologies, including argillaceous micrite, burrowed siltstone, calcareous mudstone, crinkly-laminated limestone/shale and fine oosparite. Gypsum is well preserved in this unit in various forms in beds commonly 2-5 ft (.6-1.5 m) thick. The top contact of the Basal Transition Beds (965 ft) is placed at the top of the highest gypsum bed (2 ft, 60 cm thick). Above this is a thick succession of alternating micrite and shale beds (Micrite Unit).

At Roscommon only c.12 m (38 ft) of Basal Transition beds was penetrated at the bottom of LR/EE-3. The unit consists mainly of interbedded greenish mudstone and siltstone, with minor sandstone and several beds of well preserved gypsum up to 80 cm (2.5 ft) thick. Micrite is present only as small remnants within the gypsum, so there is much less of a transition up into the overlying Micrite Unit than at Strokestown. The contact at 223.3 m is placed at the base of the lowest micrite bed, c.30 cm thick, 1 m below the main sequence. Gypsum beds up to c.1.2 m (4 ft) thick continue up section for another 10 m (33 ft).

Although the top of the Basal Transition Beds is placed in these two holes at the base of the main Micrite Unit, the lithology below the contact at Roscommon is most similar to the middle unit of the Basal Transition Beds at Strokestown (1016-1102 ft). The upper unit has more micrite and resembles the bottom of the Micrite Unit at Roscommon in having thick evaporite beds. It is possible, therefore, that the base of the Micrite Unit at Roscommon is older and passes north into Basal Transition Beds.

2.3.e Summary of the Basal Transition Beds.--- Basal Transition Beds are thickest in the eastern and north-western parts of the North Midlands Province; in the central area they thin across the top of a thickened lobe of Basal Sandstone. In the eastern area the succession thins northwards towards a shoreline, as limestone units die out and shale becomes less calcareous. Sandstone units, which are thick at Sion Hill, thin north and east from there; they may be tongues extending from the Basal Sandstone lobe to the west. Basal Transition Beds in the north-west differ substantially in lithology from eastern successions, and reflect a more restricted environment. Gypsum beds up to 5 ft (1.5 m) thick are common; limestone is a minor component (mainly thin argillaceous micrite beds); some mudstone beds are green or red. Sandstone is dominant in the lower part, in strong contrast to the shoreward successions in the eastern area.

2.4 The Pale Beds

2.4.a The Pale Beds at Navan.--- The Pale Beds were first named at Navan, where they are the main host unit of the Zn-Pb orebody. They have been extensively drilled and are better known than equivalent units elsewhere in the North Midlands Province. At Navan they consist of c.700 ft (210 m) of dominantly sandy, skeletal, oolitic and intraclastic calcarenites, micrite, and lesser argillaceous calcarenite, sandstone, dark siltstone and shale. The bottom contact is usually sharp, but can be interfingering with the underlying Muddy Limestone. The top contact is placed at the lowest shale bed (usually 1 ft, 30 cm, thick or more) in the overlying Shaly Pale Beds. This contact is usually sharp, but in some cores one or two shale beds less than 1 ft thick are present below the main sequence.

The basal part of the Pale Beds consists mainly of micrite with subordinate shaly, silty and pelletal micrites, together constituting the "Micrite Unit". The top of this unit is highly diachronous within the mine area, giving a thickness range of approximately 10-180 ft (3-55 m), thickest in the south-west. Thin isolated micrite beds occur above the Micrite Unit, where this is thin.

Within the Pale Beds a number of marker beds have been recognized (see Navan column, fig. 3), of which the Upper Dark Marker, a black shale usually c.10 ft (3 m) thick, is the most widespread and useful for correlation beyond Navan. Beds above the Upper Dark Marker are generally sandier than below it, and are termed the "Upper Pale Beds". Apart from the micritic base and sandier top, no general lithological trends have been recognized within the Navan Pale Beds.

There are no reefs in the Pale Beds (cf. Andrew & Ashton, 1982, p.36). The depositional environment inferred for most of the Pale Beds is a shallow-water, high-energy one, in contrast to deep, quiet-water conditions for Waulsortian reefs (Lees, 1982; Miller and Grayson, 1982). However, very large (30 ft, 9 m +) blocks of reef are present within the Boulder Conglomerate (Arundian?) in parts of the Navan area, and these can lie at the same apparent stratigraphic level as Pale Beds, where the Visean unconformity has cut low enough. Reef blocks are usually accompanied by debris from other units above the Pale Beds.

2.4.b Pale Beds West of Navan.--- West of Navan successions similar in a general way to the Pale Beds can be traced across the North Midlands Province, where they have been termed "Mixed Beds", "Mixed Micritic Unit", etc., by the companies. The term "Pale Beds" is applied in this paper. The base, as at Navan, is usually fairly sharp at the base of a thick micritic sequence (the Micrite Unit), though at Strokestown it is more gradational. The top of the Pale Beds in most areas is clearly marked by the base of the Upper Sandstone, a unit not present at Navan or Sion Hill. (As the Upper Sandstone separates Pale Beds and Shaly Pale Beds, it has probably developed at the expense of one or both of these; see discussion on p.23).

The top of the Micrite Unit is not clearly defined. Relatively thick sections of micrite at the bottom of the Pale Beds are commonly separated from one or more higher micrite sections by other units of varying thickness. The thickness, composition and relative importance of micrite in each succession varies widely. The term "Micrite Unit" is applied to the main, more or less continuous micrite section in each case. Interfingering with other facies on various scales becomes increasingly common upwards. The top of the Micrite Unit is therefore highly diachronous.

The Pale Beds successions vary greatly in thickness and lithological detail, and no definite correlation of component units other than the Micrite Unit has been established between the Symposium holes. However, some similar vertical trends are discernible, with regional variation in a roughly north-west/south-east direction.

In the north-west the Strokestown succession is atypical in several respects. Micrite predominates in the bottom one-third (BB.82-4, 816-965 ft), but is exceptionally scarce above. The upper two-thirds (475-816 ft) is composed largely of fining-up, 5-25 ft (1.5-7.5 m) units of massive sandstone, burrowed silty sandstone, siltstone and mudstone, sometimes with a capping of banded micrite. Part of the section (mainly c.686-756 ft) is coloured liver-red, pink and green. Gypsum is common, both in the coloured beds and below, generally as thinner beds than those below the micrite and as cross-cutting satin-spar veins.

The Newtown Cashel and Granard successions, by contrast, have micrite predominating from the base practically up to the Upper Sandstone, with two or three sandstone beds 5-15 ft (1.5-4.5 m) thick in the upper half. Lough Sheelin appears to be very similar, but LS-14 was not logged in detail at this level. Between this north-east-trending line of holes and Strokestown the Roscommon succession is intermediate in character. Gypsum beds up to 3 ft (1 m) thick are present in the lowest micrite beds. Micrite predominates in the lower half and there are several higher units up to 10 ft (3 m) thick. Sandstone beds are intercalated as at Newtown Cashel. Oolite beds up to 10 ft (3 m) thick occur at, and just above, the base of the Upper Sandstone, which is a feature more typical of the southern holes.

The Pale Beds in the two Keel holes are partly dolomitized and faulted. Micrite apparently only predominates in the bottom 50 ft (15 m)(KA-158, 1231-1282 ft), but extends up discontinuously to within c.50 ft (15 m) of the Upper Sandstone. Oolites are present near the top, but in beds no more than 8 ft (2.5 m) thick. Sandstones up to 15 ft (4.5 m) thick are distributed as at Newtown Cashel and Granard.

At Ballinalack thick micrite units are present high in the succession as well as at the base. Sandstone beds are common, but thinner than at Keel. Oolite is again present as thin beds near the top. Crinoidal calcarenite and shelly biosparite are more obvious in the lower half of the succession than to the north, though dolomitization at Keel may mask similar beds. An exceptional feature in B-109 is a thick sequence (75 ft, 23 m; 1458-1533 ft) of dark, burrowed siltstone and sandstone, which changes facies within the Ballinalack area. (The down-hole depths in B-109 at 1403 and 1458 ft are shown at the same level in figure 3, because an intervening sill has been omitted).

At Moyvore micrite again predominates in the lower half, and scattered units up to 15 ft (4.5 m) thick are present up to the base of the Upper Sandstone (184 ft in MV-8). In this succession oolite is much more important, both near the top and in one main unit c.40 ft (12 m) thick half way up (332-372 ft). Another special feature is the development of a 99-ft (30 m) thick sandstone sequence (200-299 ft) below the highest micrite. This is similar to the Upper Sandstone in character, though more of it is skeletal; both sandstones include thin oolite beds. This lower sandstone has a thinner counterpart at Ballinalack (B-109, 1267-1310 ft) and a less distinct one at Keel, and is excluded from the Upper Sandstone partly because of that. (This somewhat arbitrary distinction is further discussed in connection with the Upper Sandstone, p.23). MV-8 has a 15-ft (4.5 m) burrowed, dark silty sandstone unit (384-399 ft) in a similar position to the much thicker sequence in B-109 (1458-1533 ft). This unit, combined with others, shows a crudely matching succession in the two holes, though with some thickness and facies changes.

The Crossakeel succession is notably thinner then those in neighbouring Symposium holes, but shows the familiar pattern of micrite being almost exclusive in the lower half, and important in the upper half. Sandy oolite beds up to 11 ft (3.4 m) thick are again present near the top. A black calcareous shale 6 ft (1.8 m) thick in CK-2 (797-803 ft; faulted equivalent at 870 ft in CK-6) immediately above the oolite may be the Upper Dark Marker of Navan. The top of the Pale Beds is placed at 851 ft in CK-6, where a 14-ft (4.3-m) unit of coarse biosparite and sandy calcarenite is overlain by a thin (22 ft, 6.7 m), but otherwise typical, Upper Sandstone. Only minor sandstone beds are present within the Pale Beds at this locality, as at Sion Hill.

At Sion Hill thick micrites are present at the bottom and in the middle of the succession, but there is only a single bed 4 ft (1.2 m) thick within the top 140 ft (43 m). Oolite units are well developed not only near the top (33 ft, 10 m in SH-42, 135-168 ft), but also at lower horizons, including at 9-ft (2.7 m) bed at 397-406 ft. Crinoidal limestone is common for over 100 ft (30 m) from just above the Micrite Unit (top at 418 ft); i.e. lower in the succession than in holes to the north and west (except Oldcastle). Apart from the thicker micrites in the upper half of the succession, the Sion Hill Pale Beds are more like those at Navan in general character than any other Symposium holes. However, no detailed correlation has been established.

The Oldcastle succession in LS-58 is anomalous in that, apart from micrite at the base (approximately 75 ft, 23 m thick; correlation with LS-59 is imprecise), the succession is dominated by a wide variety of sandy, silty and argillaceous calcarenites, silty sandstone and shale, burrowed siltstone and minor micrite and oolite. The relative thinness of the basal micrite and variety of lithologies above it are strongly reminiscent of Navan. This succession may not be typical of the Oldcastle area, as thick sequences of birdseye micrite have also been drilled there. The lithologies in LS-58 are generally more open-marine in origin than the micrite, and could reflect some form of local channel or embayment in an area of tidal mudbanks.

2.4.c General Trends within the Pale Beds.--- The main trends that emerge from a comparison of the Pale Beds successions in these particular holes are as follows. Everywhere micrite predominates in the bottom one-third to one-half of the succession. Along a central north-east-trending axis from Newtown Cashel to Lough Sheelin micrite predominates right up to the base of the Upper Sandstone. North-westwards from this axis sandstone and silty shale become increasingly important at the expense of micrite in the upper half to two-thirds of the succession, culminating in a remarkable sequence of fining-up sandstone-to-mudstone units at Strokestown. South-east of the axis micrite also decreases in importance in the upper part of the successions, where it is replaced particularly by oolite and sandstone beds 10-15 ft (3 - 4.5 m) thick. Marine sandstone with interbeds of biosparite and oolite increases in total thickness southwards to Moyvore, but almost disappears eastwards towards Crossakeel and Sion Hill. At Navan it is a minor constituent below the Upper Pale Beds. (This pattern is reminiscent of sandstones in the Basal Transition Beds). Fully marine limestones, particularly oolite and crinoidal calcarenite, become increasingly abundant in mid section towards the south, especially at Moyvore, Sion Hill and Navan.

In the absence of time-controls within these successions, interpretation of facies relationships is generalized. The successions do not represent simply a northward-shifting transgressive sequence. Although diachronism is important on a local scale, the Pale Beds as a whole reflect a relatively stable general depositional environment, having stronger marine influence in the south, and a marginal-marine, locally terrestrial influence in the north and north-west.

2.4.d Variations in the Micrite Unit.--- North-west/south-east changes can also be seen in the Micrite Unit, which is very varied both laterally and vertically. It is common for the main basal micrite sequence to be more argillaceous at the bottom and become progressively cleaner, paler and more uniform upwards, culminating in birdseye micrite. In southern holes such as Ballinalack, Moyvore and Sion Hill, this trend is expressed as:

Upper part: thick (20 ft+, 6 m) uniform sections of pale micrite with well developed birdseyes. Rhythmic birdseye micrite at Crossakeel.

Lower part: interbedded more, and less, argillaceous micrites, often with only small proportions of shale. Micrite types include: a) very stylolitic micrite, grading to a form of conglomerate; b) moderately dark grey, homogeneous micrite; c) dark, "granular" micritic limestones, probably mainly pel- or intra-micrite and sandy pelmicrite.

In more northerly successions, of which Strokestown is an extreme example, the trend is typically:

Upper part: relatively clean micrite, some with birdseyes, which tends to include a high proportion of internal sediment, often green and non-calcareous.

Lower part: (often including the bulk of the sequence): rhythmic alternations of variably calcareous, black to dark grey shale, grading up and down into variably argillaceous micrite, in couplets 2-10 ft (.6-3 m) thick, with evaporites in places.

Intermediate types of succession are common, and the distribution pattern is complex. On a local scale rapid changes from thick birdseye micrite to much more varied successions, usually with common intraclastic calcarenite, have been reported within several drilling areas by company geologists (including Oldcastle; see above). The micrite succession at Granard (GR-5) is exceptional in that the lowest 63 ft (27.4 m; 581-644 ft) is much less argillaceous than the overlying micrite (460-581 ft). However, within this cleaner section the upper half alone consists of birdseye micrite.

The "north-south" variation in the Micrite Unit supports the conclusion from the Pale Beds as a whole that lateral facies changes occur within a fairly stable general depositional belt, and reflect a northward approach to shoreline conditions.

2.4.e Variations in Higher Micrite Beds.--- The thinner units of micrite in the upper parts of the Pale Beds successions also show "north-south" variation, but as mixed lithologies are present normally, only general tendencies are discernible. Usually these higher units, typically 10-40 ft (3-12 m) thick, are more argillaceous than the upper parts of the main Micrite Unit. In south-eastern holes (Sion Hill, Crossakeel) the higher micrites are only moderately argillaceous and are often capped by birdseye micrite. Further north-west the micrites are more argillacoeus and rarely have birdseyes. Some are associated with features suggesting abnormal salinity, such as serpulids, ostracods and stromatolites. Thinly banded micrite with shale partings is a characteristic minor component of the highest micrite units in many holes and can be accompanied by interbeds of ostracod biomicrite small ?-stromatolite domes with intergrown serpulids, and micrite breccia. Oncholites are common in some argillaceous micritic units in the upper half of the Pale Beds; they are also well developed locally near the base of the Micrite Unit at Navan and Sion Hill.

An overall north-westward trend from relatively clean to more argillaceous, probably shoreward micrites is evident, as in the main Micrite Unit.

2.5 The Upper Sandstone

Across the Pale Beds in all but the south-eastern part of the North Midlands Province is an exceptionally thick (up to 150 ft, 46 m), relatively uniform sandstone, termed the "Upper Sandstone". It typically consists mainly of pale grey, weakly to non-calcareous, poorly laminated, medium to coarse grained sandstone, with scattered bands of coarse biosparite, especially in the upper part. Top and bottom contacts are usually sharp, but may grade out through a few feet of sandy calcarenite. Where thinner (5-10 ft, 1.5-3 m) sandstone beds of the same type lie not far below, the bottom contact of the Upper Sandstone has been placed at the base of the main unit.

Within the Upper Sandstone isolated units of other lithologies up to c.10 ft (3 m) thick often occur near the middle; these include dark siltstone or silty sandstone, argillaceous micrite or oolite. In the Roscommon cores there are two such units. At Oldcastle (LS-58, 222-246 ft) a thicker middle unit consists of 11 ft (3.3 m) of argillaceous crinoidal calcarenite below fine silty calcarenite and sandstone interbeds. Beds up to c.2 ft (60 cm) thick of similar lithologies occur rarely at other levels in some cores.

At Moyvore two sandstone units c.100 ft (30 m) thick (MV-8, 82-184 ft; 200-299 ft) are separated by c.16 ft (4.8 m) of micrite. The bottom 50 ft (15 m) of the upper unit includes thin beds of oolite and biosparite; the bottom 25 ft (6.3 m) is also exceptionally silty. The lower sandstone unit is less uniform and more calcareous than the Upper Sandstone usually is, and includes a higher proportion of biosparite and oolite beds. Only the upper unit is placed in the Upper Sandstone. The resulting thickness is similar to that at Keel and Ballinalack, where there are also lower sandstone units, though thinner than the Upper Sandstone. A slight thinning of the intervening micrite in the vicinity of Moyvore could produce a sandstone unit of double the normal thickness.

The approximate southern limit of the Upper Sandstone is shown on the map (fig. 1). The lens-like form in figure 3 is due to the line of section. The distribution at the west end of the province is uncertain; the sandstone may extend across to Dunmore as a unit less than 20 ft (6 m) thick (fig. 2). North-westwards the unit is well represented at Strokestown. North of Navan the equivalent is probably the Rockfield Sandstone in the Kingscourt Outlier (George et al., 1976, fig. 17).

The lateral equivalent of the Upper Sandstone in the Sion Hill succession (fig. 3) appears to be the uniform unit of interbedded silty shale and biosparite (SH-43, 502-580 ft; 78 ft, 23.7 m thick), lying between typically varied Pale Beds below and Shaly Pale Beds above. It is over- and under-lain by shale beds similar to those above and below the Upper Sandstone at Crossakeel (CK-6, 815-818 ft, 868-872 ft; see fig. 3). The lower of these shales is similar to the Upper Dark Marker at Navan, especially in CK-2 (797-804 ft), where it is 7 ft (2.1 m) thick and includes diffuse carbonate bands. This suggests a possible correlation of both the uniform unit at Sion Hill and the Upper Sandstone with the Upper Pale Beds (p.17) at Navan. However, the latter are much thicker and more varied than the Sion Hill unit and include a substantial sandstone, the Upper Sandstone Marker, 15-20 ft (4.5 - 6 m) thick. Faunal data or intermediate successions are required, to confirm this correlation.

In any case regional correlation of the Upper Sandstone is more complicated, because in successions to the north-west, such as Oldcastle and Granard, only the uppermost part of the Shaly Pale Beds survives above the Upper Sandstone. This suggests that the Upper Sandstone has thickened-up north-west of Crossakeel at the expense of the Lower and Middle Shaly Pale Beds, as well as possibly being equivalent to the Upper Pale Beds; the top of the Upper Sandstone appears to get younger northwards.

2.6 The Shaly Pale Beds

2.6.a Shaly Pale Beds at Navan.--- A sequence of shale, sandstone and limestone beds 365 ft (111 m) thick sharply overlies the Pale Beds in the Navan area (fig. 3), where the term "Shaly Pale Beds" (more widely known as the "Shaly Pales") was first applied to it. Three main sub-divisions have been recognized. The Lower Shaly Pales includes three main rhythmic units c.30 ft (9 m) thick, each consisting of basal sandstone, overlain by interbedded argillaceous limestone and skeletal shale, and on top a black unfossiliferous siltstone-laminated shale up to c.3 ft (1 m) thick. The base of the Shaly Pales is placed at the bottom of the lowest shale; the lower part of the lowest rhythm thus lies within the Upper Pale Beds. There is weak rhythmicity towards the top of the Upper Pale Beds in some cores, where shales less than 1 ft (30 cm) thick can be present. The contact is otherwise usually sharp.

The Middle Shaly Pales is composed of a variety of lithologies. Distinctive in the lower half are stick-bryozoan calcarenite; shale and limestone with a rich and varied bryozoan fauna, including thick encrusting colonies at one horizon; and one notable bryozoa-rich shale 25 ft (7.6 m) thick. The upper half of the Middle Shaly Pales is largely composed of burrowed fine sandstone, siltstone and fine silty calcarenite, some of it argillaceous. (This particular facies is widely distributed through the North Midlands Province.) The top bed at Navan is a fine sandstone over 10 ft (3 m) thick.

The Upper Shaly Pales consists of interbedded crinoidal calcarenite and shale, with some laminated calcareous siltstone and silty calcarenite near the bottom. Burrowing is much less common than in underlying beds. The shale beds are the really distinctive feature. Individual beds can be over 10 ft (3 m) thick; they are black, unfossiliferous, commonly have scattered bands of pale, finely laminated siltstone up to 1/2 inch (1.5 cm) thick, and often include one or two bands of "beef" (sheets parallel to bedding 1-2 in (2-5 cm) thick of diagenetic calcite with vertical fibrous texture). The unfossiliferous shale beds in the Lower Shaly Pales are also of this type, but accompany different lithologies. The top contact of the Shaly Pales is sharp at the top of the highest thick shale (Selection Trust core L.6, 214 ft), and is overlain by a thick relatively uniform crinoidal calcarenite (basal part of the Argillaceous Bioclastic Limestone in this area).

2.6.b Upper Shaly Pale Beds Marker in the North Midlands Province.--- West of Navan a group of relatively thick shales of Upper Shaly Pales type can be traced from hole to hole across most of the North Midlands Province. The top of these shales provides the datum in figures 2 and 3. The highest shale is not always a thick one; in some sections an arbitrary lower thickness limit of 1 ft (30 cm) has been used to define the top. The shales are correlated with the Upper Shaly Pales at Navan on the basis of their similar appearance, their relative abundance, and the rapid change above them into sandy limestone beds different from those below.

The underlying part of the Shaly Pales succession changes character more radically westwards from Navan and correlation becomes less certain. Hence the highest shales are of particular importance for correlation across the North Midlands Province. Uncertainties over the correlation of the Upper Shaly Pales in the succession at Moyvore are discussed below (p.28).

2.6.c Variation in the Lower Shaly Pale Beds.--- The distinctive cyclic sandstone-to-shale units of the Lower Shaly Pales at Navan are not present in the Symposium holes further west, though typical silt-banded shales do appear in a few holes. The changed successions between Upper Sandstone and identifiable Middle and Upper Shaly Pales are not always clearly assignable to either Lower or Middle divisions. The progressive loss of the Lower Shaly Pales westwards is shown by the cores between Navan and Keel.

At Sion Hill a 4-ft (1.2 m) black shale with "beef" and thin siltstone bands (SH-43, 498-502 ft) is taken as the basal bed of the Lower Shaly Pales. It is overlain by a 39 ft (12-m) sequence (463-502 ft) of biosparite, silty calcarenite, units of thinly interbedded limestone and shale, locally with abundant brachiopods, and black shale beds up to 2 ft (60 cm) thick similar to the basal one. The top contact is gradational into the more uniform beds above. Apart from the lack of sandstone and obvious cyclicity, this sequence is generally similar to the Navan Lower Shaly Pales. This correlation is supported by the relative position of these beds 100 ft (30 m) below typical Upper Shaly Pales.

Similar lithologies and relative stratigraphic position identify the much thinner (slightly faulted) Crossakeel sequence in CK-6 (808-829 ft) as probable Lower Shaly Pales. The identification at this locality is important as a control on the correlation of the underlying Upper Sandstone with the Upper Pale Beds.

At Ballinalack the distinction between Lower and Middle Shaly Pales is less clear. Just above the Upper Sandstone siltstone-banded shale beds up to 5 ft (1.5 m) thick, typical of the Lower Shaly Pales, are scattered through a sequence of burrowed silty calcarenite and calcareous siltstone beds (B-109, 1149-1188 ft), which at Navan is a Middle Shaly Pales facies. A few similar shale beds occur above (1120-1130 ft), interbedded with stick-bryozoan calcarenite typical of, and here interpreted as, the lower part of the Middle Shaly Pales. The fading distinction between Lower and Middle Shaly Pales reflects the regional northward facies change at this level.

At Keel the Lower Shaly Pales are almost unrecognizable. A 2-ft (60-cm) black shale with siltstone bands (KA-158, 1001-1003 ft) is present 10 ft (3 m) above the Upper Sandstone, underlying typical Middle Shaly Pales. In "northern" holes no Lower Shaly Pales are differentiated.

2.6.d Variation in the Middle Shaly Pale Beds.--- The Middle Shaly Pales also show a pattern of decreasing diversity westwards from Navan. The unit is represented in most holes largely by rather uniform sequences of silty calcarenite and siltstone, often burrowed, as in the upper half of the Middle Shaly Pales at Navan. Thin beds of shelly biosparite are common locally. In general these successions lack the more varied, bryozoa-rich shale and limestone characteristic of the lower part of the Navan Middle Shaly Pales, though some beds can be present. The sandstone bed at the top of the Navan Middle Shaly Pales is not present in other Symposium holes, so the top contact is generally placed at the bottom of the lowest overlying thick (2-3 ft, .5-1 m) shale. This coincides with the top of the typical Middle Shaly Pales facies except at Sion Hill, where an abrupt upward increase in thinner shale interbeds marks the top (SH-43, 363 ft).

Some exceptional features are as follows. The Sion Hill succession (SH-43, 363-463 ft) includes more fossiliferous shaly limestone and less burrowing than is normal further north or at Navan, probably reflecting a more seaward position. The Crossakeel sequence (CK-6, 718-808 ft) is more varied than Sion Hill, but bryozoa-rich shale and limestone are barely represented. The Ballinalack succession (B-109, 1067-1149 ft) includes stick-bryozoan calcarenite beds in the bottom 20 ft (6 m), and is more like Navan than any other Symposium hole. At Keel (LF-16, 1628-1745 ft; base faulted) biosparite is important in the lower half. In the "northern" holes other than Crossakeel and Roscommon it is not practical to differentiate Middle Shaly Pales at all; the successions are much thinner.

2.6.e Variation in the Upper Shaly Pale Beds.--- The Upper Shaly Pales in "southern" holes are generally similar to those at Navan, but thinner. Both argillaceous and cleaner silty calcarenites form the predominant constituent of the unit; their relative importance varies, but without obvious pattern. The characteristic black, unfossiliferous, siltstone-laminated shale beds also vary in abundance and thickness from hole to hole. Shale beds of this type up to 5 ft (1.5 m) thick are fairly common, but several holes also have one exceptionally thick shale (10-15 ft, 3-4.5 m) in the lower half of the unit. It is not clear whether this is the same bed in each case, because the relative thickness and distribution of the other thick shale beds show no pattern. In most cases top and bottom contacts of the Upper Shaly Pales are naturally defined by the limits of common black shales over 2 ft (60 cm) thick. Upper Shaly Pales are identified as follows:

	Thickness	Normal shale max.	Exception
Sion Hill SH-43,255-363ft Calcarenite dominantly argillaceous	100ft/30m,	4ft/1.2m	15FT/4.5M
Crossakeel CK-6,633-718ft, Calcarenite less argillaceous than Sion Hill	85ft/26m	5ft/1.5m	10ft/3m
Ballinalack B-109 1000-1067ft Shale makes up over 50% of the Upper Shaly Pale Beds	67ft/20.4m	6ft/1.8m	10ft/3m
Keel LF-16 1545-1628ft Shale very subordinate, except in scattered thick beds. Calarenite predominantly silty.	83ft/25.3m	8ft/2.4m	13ft/3.9m

2.6.f Shaly Pale Beds in "Northern" Holes.--- In "northern" holes, except Crossakeel and Roscommon, the Shaly Pales are very much thinner than to the south, and can seldom be usefully subdivided; in some holes they are barely recognizable. Isolated, relatively thick black shale beds of Upper Shaly Pales type are often the only guide. The sequences rest directly on Upper Sandstone. The main lithology is fine silty calcarenite with interbeds of coarse shelly biosparite. Finely laminated calcareous siltstone and thin silty shale beds can also be present.

At Oldcastle (LS-58, 143-191 ft; 48 ft, 14.6 m thick) one black shale 7 ft (2.1 m) thick is accompanied by several less than 18 ins (45 cm) thick. The top contact is placed at the top of the main lithology rather than a shale bed. At Lough Sheelin (LS-14, 620-677 ft; c.57 ft, 17.3 m thick with some core loss) the lithologies and boundaries are similar, but there are also two beds of fine sandstone 6 ft (1.8 m) thick. At Granard (GR-20, 768-789 ft; 21 ft , 6.4 m thick) the unit is recognized on the basis of typical shale, only two beds reaching 2 ft (60 cm) thick, one defining the top. At Newtown Cashel the unit immediately above the Upper Sandstone (L-24, 52-91 ft; 39 ft, 11.8 m thick) is more argillaceous; shale beds are up to 9 ins (23 cm) thick only, one of them marking the top. This unit is identified as Shaly Pales because of its stratigraphic position, and the absence of similar thin shale beds above it. At Strokestown the only representative of the Shaly Pales is a 15-ft (4.5-m) sequence (BB-82-4, 365-381 ft) of silty calcarenite and typical shale, the top one being 6 ft (1.8 m) thick. The Shaly Pales have lost their identity in the Mount Bellew and Dunmore successions.

The Roscommon succession is anomalous for this north-western area in having over 100 ft (30 m) of beds assignable to the Shaly Pales (GR-1, 95.7-129.2 m). A lower sub-unit 9 m (30 ft) thick (top at 120.2 m), lying directly on the Upper Sandstone, consists of uniformly very fine silty calcarenite and laminated calcareous siltstone, with biosparite near the top and bottom. Burrowing is uncommon, but the absence of shale suggests correlation with the Middle Shaly Pales. A 2-ft (60-cm) dark grey calcareous shale overlies this and marks the base of the upper unit, which is typical of other "northern" holes. Near the top are two dark grey shales c.5 ft (1.5 m) thick with rare siltstone bands. These are atypical of the Shaly Pales in being calcareous. The top contact is placed c.10 ft (3 m) above the higher shale, where there is an increase in argillaceous limestone and shale. The reason for the anomalous thicknesses of both Shaly Pales and Upper Sandstone at Roscommon (fig. 2) is obscure at present.

2.6.g Correlation of Shaly Pale Beds at Moyvore.--- The Moyvore Shaly Pales succession is discussed separately, because correlation on the basis of lithologies alone is problematical. The succession above the Upper Sandstone shows departures from the pattern to the east and north, and two different correlations can be proposed. The first is shown in figure 3. Several black shales up to 5 ft (1.5 m) thick with well developed "beef" bands occur in a 60-ft (18-m) sequence (MV-12, 440-500 ft), which lies above the Upper Sandstone by about the same amount as at Keel and Ballinalack. This sequence is correlated with the Upper Shaly Pales on the first interpretation. The underlying succession down to oolitic beds just above the Upper Sandstone consists of silty calcarenite with subordinate shelly biosparite and one thick sandstone (MV-11, 212-228 ft), Amax' "Sandstone Marker". These beds are mainly of Middle Shaly Pales type; the sandstone is comparable with the highest bed in the Middle Shaly Pales at Navan. The oolitic beds are a local peculiarity.

The difficulty with this correlation is that the "beef" shales are overlain by a thick succession also of Shaly Pales type. This consists of at least 200 ft (60 m) of very silty calcarenite (MV-12, 258-440 ft with a fault at c.315 ft) of Middle Shaly Pales facies, which is overlain by nearly 200 ft (60 m) of argillaceous calcarenite with scattered shale beds 5-20 ft (1.5-6 m) thick. The shales contain scattered laminated siltstones and a few "beef" bands, and are thus very similar to those in the Upper Shaly Pales elsewhere.

On the second interpretation these higher shales are correlated with the Upper Shaly Pales, the lower ones with the Lower Shaly Pales. The two thick sandstones are regarded as older than the Upper Sandstone to the north, which is represented by the Sandstone Marker. The whole Pale Beds-Shaly Pales succession on this interpretation is over 1000 ft (300 m) thick, as it is at Navan (Sion Hill c.750 ft, 228 m). The thickness would be nearly double that at Keel (c.550 ft, 168 m) and imply a substantial downwarp in the Moyvore area.

In the absence of faunal data, the first interpretation (fig. 3) is favoured here, partly because the Shaly Pales/Upper Sandstone interval at Moyvore fits more closely the pattern at Keel and Ballinalack and partly because there is preliminary evidence that the problematical upper set of shales may be a local development. In B-114 at Ballinalack, located on the opposite, downthrown side of the main Ballinalack Fault (Jones and Bradfer, 1982) to B-109, a group of thick shales is present between c.845 and 912 ft in a faulted sequence c.200 ft (60 m) above Upper Shaly Pales (top at c.1048 ft). The shales contain thin laminated siltstone bands, and closely resemble both those in the Upper Shaly Pales and the upper shales at Moyvore. More work is required to establish the local correlation of the Ballinalack shales in a unfaulted succession, and their distribution pattern. Location on the downthrown side of the fault may not be the control. It could be that at both Moyvore and Ballinalack the upper set of shales has accumulated in a local basin, formed in the preliminary stages of late Tournaisian/early Visean fault movements. The Tynagh Iron Formation (Schulz, 1966, fig. 3), appears to have accumulated in a basin of this kind.

If the correlations shown in figure 3 are correct, it remains to explain the prodigious amount of fine quartz in the succession above the Shaly Pales at Moyvore, which is absent at this level in successions to the north (Keel, Ballinalack); a westerly source seems to be implied. The quartz is not anomalous on the second interpretation, as these beds are similar to Middle Shaly Pales elsewhere.

2.6.h Summary of the Shaly Pales.--- The three-part division of the Shaly Pales, established at Navan, is discernible only in the adjacent Symposium holes at Sion Hill, Crossakeel and Ballinalack; in these the Lower Shaly Pales are less clearly rhythmic. The Middle Shaly Pales are recognizable over a wider area, but mainly as the burrowed silty calcarenite facies of the upper part of the unit at Navan. The Middle Shaly Pales are not recognizable in the "northern" holes, where the Shaly Pales range in thickness from 15-57 ft (4.5-17.3 m) only. The Roscommon succession is exceptional in this belt in being thicker and more differentiated. The overall pattern of northward thinning and successive loss of lower units is interpreted as due partly to lateral passage into the Upper Sandstone, partly to slower subsidence. The Shaly Pales ultimately disappear northwards and westwards, being unrecognizable in the

Dunmore Province. Southwards they lose their identity in a poorly differentiated succession dominated by silty calcarenites extending from Pale Beds up into Argillaceous Bioclastic Limestone (e.g. at Windmill Hill).

2.7 The Argillaceous Bioclastic Limestone

Between the Shaly Pales and the base of the reef, where present, is a thick succession of variably argillaceous limestone and calcareous fossiliferous shale, termed here the "Argillaceous Bioclastic Limestone" (A.B.L.). The A.B.L. successions show a general upward change from relatively clean, sandy or silty limestone at the bottom, through argillaceous crinoidal limestone and thin shales, into much more argillaceous, finer-grained limestone and thicker calcareous shales in the upper half. These are followed by a transitional sequence of cleaner cherty limestone with thin shaly interbeds just below the reef. The successions can be subdivided on the basis of relatively subtle lithological variation and bedding types into units that have proved useful for correlation within drilling areas and sometimes across distances of 10 miles (16 km) or so. However, lateral variation in the successions has prevented most units being followed further. In consequence the A.B.L. is not subdivided here, except for a basal sequence, which can be related easily to the Shaly Pales datum.

The bottom contact of the A.B.L. is generally distinct at the highest thick shale bed in the Shaly Pales. At Moyvore the distinction between A.B.L. and Shaly Pales is less clear, and two quite different interpretations of the contact are possible (see above). Figure 3 shows the preferred one. The problem of defining the top contact of the A.B.L. in successions without reefs is considered in the next section; similar lithologies are present in beds younger than the reefs.

Evidence for diachronism at the base of the reef is common. Isolated beds of pale, reef-like biomicrite a few feet thick with poorly developed stromatactis can occur well below the reef in individual cores; e.g. 80 ft, 24 m below at Keel (LF-16, 979-987 ft). At Sion Hill a 12-ft (3.6-m) thick reef bed (SH-16, 856-868 ft) lies below some 200 ft (60 m) of shaly beds, above which bryozoan shales alternate with reef tongues of varying thickness, probably in a reef-margin situation. In other holes pale biomicrite beds without stromatactis, less certainly reef-related, are also common for varying depths below the reef. Scattered coarse crinoidal limestones in the upper part of the A.B.L. may also be related to reefs.

At Navan the full thickness of the A.B.L. (originally known as the "Crinoidal Limestone Unit" there) was not established by the Selection Trust drilling, as faults cut most cores and L.6 collared below the reef. In general the Navan and Oldcastle successions are less argillaceous than those to the west. The upper part of the Navan succession in some holes is composed mainly of very coarse, reef-equivalent, crinoidal biosparite, of which the once famous Ardbraccan Limestone (building stone) is an example. This is rare in other Symposium cores.

The bottom part of the A.B.L. in most areas is distinctly less argillaceous but often sandier than above, and is thus somewhat transitional up from the Shaly Pales. The thickness of this cleaner interval is roughly proportional to that of the A.B.L. as a whole, as shown by the correlated top in figures 2 and 3. Similar beds are present in the Dunmore Province. In the Moyvore succession silty calcarenite extends to the top of MV-12; the tentative correlation with beds between 320 and 440 ft in figure 3 is based on their lower shale content than overlying beds. The absence of a clean unit above the thick shales in the upper part of MV-12 is compatible with the correlation of the Shaly Pales shown in figure 3, rather than the alternative suggested on p.29.

In a number of successions (including Sion Hill, Keel, Crossakeel, Roscommon and Strokestown) Caninia is notably common in beds just above and below the top contact of the clean unit. Michelinia is also sometimes present. In some other successions (including Granard, Lough Sheelin and Oldcastle) similar distinct concentrations of Caninia occur at a higher stratigraphic level in the A.B.L., even within 100 ft (30 m) of the tuff band.

2.8 Post-Reef Argillaceous Bioclastic Limestone

The top of the A.B.L. in successions where the reef is absent, as in most of those shown in figure 2, comes at a higher stratigraphic level than the reef-equivalent horizon. A number of quite different post-reef sequences are represented in the various cores, so definition of the top of the A.B.L. is not straightforward and at present is not fully resolved. Furthermore it is seldom clear precisely where the reef-equivalent horizon is.

Evidence that the A.B.L. extends above the reef is provided by tuff bands a few inches thick within the upper beds. Two or three tuffs occur above the reef at Ballinalack and at Keel, and at least one at Dunmore (fig. 2). None are known below the reefs. In the Granard cores two tuffs are present, differing from each other in appearance and stratigraphic context. The lower one lies in the middle of a distinctive relatively uniform argillaceous limestone unit (GR-20, 332-396 ft), referred to here as the "tuff-host unit", which belongs just above probable reef-equivalent beds. A single tuff occurs in a similar host unit at both Lough Sheelin and Oldcastle, and probably correlates. At Roscommon the situation is similar, except that the host unit is very cherty. Chert does not invalidate the correlation, however, because in one of the Granard cores it is weakly developed in the tuff-host unit. At Dunmore a tuff band occurs again in a similar limestone unit, here immediately overlying the reef, and probably correlates. This tuff is therefore regarded as an important marker for comparing the post-reef A.B.L. successions. The upper tuff at Granard is of local importance, but has not been recognized in other Symposium cores.

At Crossakeel argillaceous limestone typical of the upper part of the A.B.L. in reef-capped successions extends up to 481 ft in CK-1. This is overlain by a rather faulted sequence c.120 ft (37 m) thick of less argillaceous limestone, which, though distinctive, is not fundamentally different from underlying beds. It is sharply overlain at 360 ft by shaly limestone-boulder beds similar to the Boulder Conglomerate at Navan; this contact may well be an unconformity. The top of the A.B.L. in this succession is therefore placed at the base of the boulder beds. No tuff or recognizable reef-equivalent unit is present. The boulder beds are overlain by thin-bedded limestone and shale, scattered limestone conglomerates and platy chert. At Navan the very similar Upper Dark Limestones are of probable Arundian age. The age of the highest A.B.L. in CK-1 is not yet known.

At Oldcastle the situation is quite different. The main argillaceous succession extends up to 169 ft in LS-62, above which is the less argillaceous tuff-host unit, c.115 ft (35 m) thick. Further shaly beds overlie this in LS-52 (342-401 ft), which are not easily distinguished from some sub-reef lithologies elsewhere. A cherty sequence 300 ft (91 m) thick, quite unlike the Upper Dark Limestones, overlies this, and is in turn overlain by coarse crinoidal dolomite. This succession is reminiscent of that at Roscommon, where similar dolomite (Oakport Limestone) is probably of Chadian age. The contrast with the Crossakeel succession is very striking (fig. 2). The top of the A.B.L. could be placed at the base of the chert, but this contact is probably diachronous. The Lough Sheelin succession is similar to Oldcastle, apart from being thicker, but is eroded just above the base of the chert.

At Granard (GR-20) the succession is somewhat like Oldcastle below the chert, in that the same tuff-host unit is overlain by shale and limestone not sufficiently unlike some lower A.B.L. units to be readily differentiated. Here, however, these beds pass up through a short transition into beds similar to the Upper Dark Limestones (GR-20, c.255 ft). There is no obvious unconformity. The top of the A.B.L. must be placed here at the highest. The contrast with Oldcastle in the upper part of the succession is again striking. The upper tuff lies within the Upper Dark Limestones.

In the Roscommon succession the lower part of the A.B.L. (GR-1, 54-95.7 m) is an exceptionally uniform sequence of interbedded fossiliferous shale and fine, generally burrowed, argillaceous calcarenite, and ends abruptly on top with a shale 4 ft (1.2 m) thick (52.8-54 m). An intermediate unit 26 ft (8 m) thick overlies this, followed by a uniform cherty sequence (LR/EE-3, 111-146 m) containing the correlated tuff. The top of the A.B.L. could be placed at the base of the chert, but the boundary would then cut across units correlated by markers. Above the chert interbedded fine limestone and shale (LR/EE-3, 83-111 m) similar to parts of the A.B.L. elsewhere is overlain by dolomitic Oakport Limestone (mainly shale-free, coarse and fine crinoidal calcarenites). There is a case for extending the A.B.L. up to 83 m.

This view is reinforced by the Strokestown succession, in which typical A.B.L., including argillaceous crinoidal limestone and minor shale, extends up to the base of the Oakport Limestone (BB.82-4, 131 ft) with virtually no chert. There is no recognizable reef-equivalent or tuff. The top contact is sharp, but apparently conformable.

Further west the A.B.L. at Mount Bellew is generally similar to that at Roscommon, but here chert extends down below the reef-equivalent horizon, (according to the correlation with Dunmore; see figure 2). The problem of using chert to define the top of the A.B.L. is emphasized by this again. In addition chert occurs immediately below most reef sections in the Midlands.

Summarizing the problem of defining the top of the A.B.L. where reefs are absent, argillaceous limestone and shale, not very different from some sub-reef units, extend above the reef-equivalent horizon and are overlain by a number of quite different stratigraphic units. These include ?-Arundian Navan-type Upper Dark Limestones, both unconformable and apparently conformable; clean shelf calcarenite, notably the Chadian Oakport Limestone; and cherty limestone probably of both Chadian and Courceyan age. Where Upper Dark Limestones and Oakport Limestone or equivalents overlie A.B.L., the contact is usually clearly definable. It is less satisfactory to use the base of the cherty successions as the top contact of the A.B.L., partly because chert cuts across clearly correlatable horizons; partly because the base of the chert is not everywhere distinct; and partly because chert commonly also underlies the reef. Until post-reef shaly limestone successions are distinguished from those lower down, it seems sensible to include the chert sequences within the A.B.L. In any case, the definition should not be allowed to obscure the important lateral facies and thickness changes that are becoming apparent at, and just above, the level of the reef.

2.9 Windmill Hill Succession

The Windmill Hill succession (fig. 3) has been omitted from the foregoing discussion of the North Midlands Province, because correlation, particularly of the lower half, is not clear. The hole lies well south of the others and may be located in a transitional area or even outside the province. The hole did not reach unambiguous Pale Beds.

The upper half of the succession down to the level of the shales at 273-283 m, which in figure 3 are shown as Upper Shaly Pales equivalents, can be correlated with Moyvore. A thick zone of argillaceous dolomite in WH-1 (c.158-197 m) appears to be equivalent to the uppermost 150-200 ft (45-60 m) of the drilled Moyvore succession. Correlation below the dolomite is based partly on fairly close overall lithological similarity between the WH-1 interval 206-283 m and MV-12 184-500 ft, and partly on individual shale beds.

The latter include some 2-ft (60-cm) thick beds not shown in figure 3 in the intervals WH-1 250-254 m and MV-12 337-361 ft, as well as the supposed Upper Shaly Pales. The question of whether the latter are really equivalent to the Shaly Pales is the same as for Moyvore (p.28, above). The shales contain a few thin siltstones and one "beef" band. The succession above the dolomite is similar to the upper part of the A.B.L. in other cores, though the cherty sequence is thicker.

Between the shales at 273-283 m and the dolomite below 392.5 m is a thick succession of interbedded limestone and thin siltstone-banded shales, which can be split up into several units. The overall trend downwards is towards cleaner limestone; the unit at 368-392.5 m consists mainly of diffusely argillaceous, crinoidal calcarenite with common brachiopods --- a lithology reminiscent of the lower part of the Middle Ballysteen Limestone at Tynagh and of the upper part of the Rosenallis succession (p.52). The highest sandstone beds, c.5 ft (1.5 m) thick, occur within a sequence of burrowed siltstone and silty shale just below the dolomite (408-420 m). Correlation of this sequence with the Upper Sandstone at Moyvore seems most unlikely in view of the much thicker limestone sequence between it and the Upper Shaly Pales at Windmill Hill. It is more probable that the sandy beds correlate with sandstone lower in the Moyvore succession, somewhere between the Upper Sandstone and the Micrite Unit. According to this interpretation the Upper Sandstone has passed south from Moyvore into silty calcarenite and silty shale, as it has at Sion Hill. The dolomite at the base of the Windmill Hill succession, though possibly in fault contact, suggests that the sandy sequence is not equivalent to the Basal Sandstone at Moyvore; so does its relative depth. It is possible, therefore, that the Micrite Unit lies below WH-1.

It is concluded that the succession below the Shaly Pales changes character rather sharply southwards from Moyvore, mainly through the loss of the thick sandstones, whereas the higher part of the Windmill Hill succession is unchanged.

3. Dunmore Province

3.1 Introduction

The Dunmore succession has been excluded from the North Midlands Province, because between the basal clastics and the reef it is very much thinner (c.200 ft, 60 m), and because Pale Beds and Shaly Pales are not clearly recognizable within the thin transitional sequence below the Argillaceous Bioclastic Limestone (A.B.L.). The Mount Bellew succession below the A.B.L. is thicker and is of Pale Beds type, but Shaly Pales are absent. The extent of the Dunmore Province is not known; Mount Bellew appears to be in a marginal zone.

3.2 Dunmore Succession

The lowest beds drilled in the Dunmore succession (74-MG-2) consist of 110 ft (34 m) of pale grey, coarse sandstone, which is commonly mud-flaked, locally conglomeratic and includes a few mudstone interbeds, both apple-green and grey. This unit is similar to the Basal Sandstone at Keel, and is likewise termed "Basal Sandstone" and regarded as the top of the Old Red Sandstone. No red beds were intersected. The top contact in this hole appears to be faulted.

Following an undrilled gap, the succession is continued upwards in 74-MG-5 with a mixed unit over 25 ft (7.6 m) thick (top at 462 ft), consisting of thinly interbedded sandstone, banded siltstone and silty shale with little burrowing and very rare skeletal debris. This is overlain by a 13-ft (4-m) sandstone, mainly medium-grained, non-calcareous and whitish, but partly fine-grained, green-grey and micaceous. The position of this relatively thick sandstone in the succession suggests correlation with the Upper Sandstone of the North Midlands Province. It is overlain (432-449 ft) by a 17-ft (5.2-m) unit of shale with thin interbeds of calcareous siltstone and calcarenite. The same unit is clearly recognizable in MGR.82-35 (659-683 ft) with slight differences. Here non-calcareous, dark grey, silty shales up to 3 ft (1 m) thick include interbeds of laminated fine calcareous sandstone up to 6 in (15 cm) thick. These shales and associated beds resemble the Shaly Pales, but form a much thinner sequence. The lithologies and their relative position in the Dunmore succession are the basis for the correlation in figure 2.

Overlying beds clearly correlate with the A.B.L. of the North Midlands Province. In 74-MG-5 32 ft, 9.7 m (400-432 ft) of interbedded fine silty calcarenite and subordinate fossiliferous shale form the next unit with a gradational top. Caninia is notably common here and just above. MGR.82-35 has a thinner equivalent (647-659 ft). Similar beds at the bottom of the A.B.L. overlie the Shaly Pales right across the North Midlands Province (fig. 2).

The overlying unit consists of gradationally interbedded very fine calcarenite and dark calcareous shale with fine skeletal debris. This unit is 60 ft (18.3 m) thick in 74-MG-5 (340-400 ft), 90 ft (27.4 m) in MGR.82-35 (557-647 ft) and constitutes the main part of the A.B.L. It is overlain in both holes by a similar transitional sequence up into typical sub-reef chert: upwards from the base the proportion of shale decreases; bedding becomes thinner and commonly more diffuse; chert, mainly as poorly formed, small nodules, becomes commoner. The cherty sequence is c.120 ft (37 m) thick in 74-MG-5, c.25 ft (7.6 m) in MGR. 82-35.

The upper part of the cherty sequence is laterally equivalent to the reef, and contains reefal tongues in various forms. The thickness variation of the chert sequence is attributable to differences in stratigraphic level of the base of continuous reef. The base is relatively low in MGR.82-35, but even so 22 ft (6.7 m) below it there is a 9-in (23 cm) micrite bed with large crinoid ossicles and incipient stromatactis (at 539 ft), suggestive of reef-equivalence. 74-MG-5 lacks reef-like beds in the chert, but 74-MG-4 has a 13-ft (4-m) tongue (285-298 ft) of well developed reef, including stromatactis, at least 70 ft (21 m) below the main reef, the base of which is very gradational at c.195-215 ft. The tongue occurs at a horizon equivalent to roughly 300 ft in 74-MG-5, where there is no sign of it. The reefs themselves include tongues of reef-margin or off-reef facies in some cores. The relatively small size of the reefs in this area means that their margins are more often intersected in core than are those of the more extensive reefs to the east and south.

The succession between the reef and the Basal Sandstone in the Dunmore area, though very much thinner than in the North Midlands Province, has several similar features. The sandy and shaly transitional sequence at the bottom includes possible equivalents of the Upper Sandstone and Shaly Pales, and is overlain by A.B.L. The sub-reef chert is common to both areas, but proportionately much thicker near Dunmore. The Dunmore succession from the ?-Upper Sandstone upwards appears to be a time-equivalent, condensed version of that in the North Midlands Province. However, lateral passage of part or all of the Pale Beds and underlying units into the Basal Sandstone at Dunmore is a possibility, crossing the correlation line in figure 2. Faunal evidence is required.

The reef in MGR.82-35 is overlain by nearly 50 ft, 15 m (80-128 ft) of nodular-bedded, fine siliceous calcarenite interbedded with burrowed argillaceous very fine calcarenite and minor very calcareous shale. Chert is locally common, bed contacts are very gradational and crinoid debris is sparse. In contrast to beds below the reef, burrowing is very common and "real" shale is rarely developed. A 2-ins (5-cm) tuff lies near the middle of this sequence at 108 ft. Above 80 ft the lithologies are generally similar, but burrowing is rare, crinoid debris is more abundant and chert is absent. There is fairly close lithological similarity between the tuff-host unit in this hole and those at Strokestown, Granard (lower tuff), etc. (p.32) which are regarded as lateral equivalents.

3.3 Mount Bellew Succession

The Mount Bellew succession lacks reef, and limestone extends much further (200 ft, 60 m+) below the A.B.L. than at Dunmore. However, the A.B.L. itself is very similar in thickness and lithological succession in the two areas. The base of the A.B.L. is placed at 588 ft in AG.MB-1 at the sharp top of a sandy unit. The bottom 39 ft (11.8 m) of the A.B.L. is dominated by silty fine calcarenite as elsewhere.

The problem of defining the upper limit of the A.B.L. in the absence of reef was discussed above (p.33). The passage up into chert at c.472 ft is similar to that in the Dunmore holes. The cherty unit (245-472 ft) is probably the lateral equivalent of the chert envelope round the Dunmore reefs, but no reef-equivalent horizon is discernible within it and there is no tuff. Both the upper half of the cherty unit and the overlying unit of nodular biomicrite and very calcareous shale (205-245 ft) are somewhat similar to the tuff-host unit at Dunmore. The top of the A.B.L. is provisionally placed at the base of Oakport Limestone (112 ft in AG.MB-1).

The succession below the A.B.L. is unlike that in the Dunmore holes. It resembles some of the most northerly Pale Beds successions in the North Midlands Province, but there is no Shaly Pales unit, and the Upper Sandstone is only tentatively identified. The main units in AG.MB-1 are as follows (compare fig. 2):

46 ft (14 m)	588-634 ft	Sandstone-dominant unit with interbeds of biosparite and calcareous siltstone. Beds of fine sandstone up to 4 ft (1.2 m) thick, with one 10-ft (3.1-m) bed of uniform medium-grained skeletal sandstone at bottom.
9 ft (2.7 m)	634-643 ft	Mudstone with very minor thin silty bands.
13 ft (4 m)	643-656 ft	Burrowed silty sandstone and silty shale with minor micrite.
12 ft (3.7 m)	656-668 ft	Sandstone, non-calcareous, creamy white, medium-grained, gradational top.
44 ft (13.4 m)	668-712 ft	Mainly silty shale; less shaly overall than below 742 ft. Tends to be rhythmic. Also thin birdseye micrite, oncholites, thin micrite conglomerate.
30 ft (9.1 m)	712-742 ft	Mainly sandstone, thick-bedded, non-calcareous, pale grey, medium-grained; minor burrowed siltstone and shale.
63 ft (19.2 m)	742-806 ft	Mainly dark calcareous siltstone and silty mudstone with common very argillaceous micrite and a few sandstones 1-2 ft (30-60 cm) thick. Burrowing locally common. Some lamination may be stromatolites. Graded contacts between beds suggest crude rhythmicity.

The 46-ft (14-m) sandy unit at the top is correlated with the Upper Sandstone on the grounds of relative thickness and stratigraphic position below the A.B.L. However, the upper two-thirds includes more calcarenite and calcareous siltstone than normally, so this part could possibly be laterally equivalent to the Shaly Pales. The succession below 634 ft is of Pale Beds type, but is exceptionally argillaceous. It resembles the upper part of the Lough Sheelin succession. By analogy a more distinct micrite unit might lie below the Mount Bellew hole. The 34-ft (10.3-m) sandstone-to-mudstone sequence between 634 and 668 ft is reminiscent of the large-scale graded units that dominate more than 200 ft (60 m) of the Strokestown succession, also just below the Upper Sandstone (p.18). Rhythmicity below 742 ft is similar to that in argillaceous micrite sequences at Granard and Newtown Cashel (p.21).

The presence of this Pale Beds-type sequence at Mount Bellew suggests that the area is transitional in character between the Dunmore and North Midlands Provinces, though on present evidence it is hardly so geographically. The relationship with the Loughrea succession (fig 4) is discussed later (p.64).

4. The Limerick Province

4.1 Introduction

The Limerick Province is centred for historical reasons on north Co. Limerick, where Shephard-Thorn (1963) described the succession seen at outcrop. The sub-reef succession in this area is now much better established from core. The principal features of the province are summarised in Tables 1 and 2, and section 1.4.b.

The Limerick Province extends into the south-western part of the Symposium area, where it is represented in only slightly modified form by the Silvermines and Tynagh successions (fig. 4). Cores from Loughrea, Cloghan, Templemore, Borris-in-Ossory and Rosenallis show modified peripheral successions. Two important synchronous marker beds link some of these successions (fig. 4): the Ballyvergin Shale and the Fine Calcarenite Marker, both low in the succession. No extensive markers have yet been identified in the main part of the Ballysteen Limestone.

4.2 Old Red Sandstone

Much thicker Old Red Sandstone sequences are present in the Limerick Province than were encountered in most Symposium holes in the North Midlands Province. A widespread top unit of pale grey sandstone is closely comparable with that in the North Midlands Province, and is likewise termed "Basal Sandstone". Underlying beds, in most areas dominantly red but with some pale grey units, are included together as "Red Beds". Isolated red siltstone beds a few feet thick occur only rarely within the Basal Sandstone.

In the Silvermines area the Old Red Sandstone is 300-350 ft (90-105 m) thick and can be subdivided (Rhoden, 1958; Taylor and Andrew, 1978), though not with regional application (Bruck, 1982). In core V.40 30 ft (9 m) of Red Beds, dominantly siltstone, locally with caliche, forms the lowest penetrated unit. This is sharply overlain by 73 ft, 22 m (885-958 ft; faulted at 903 ft) of Basal Sandstone: pale grey to whitish sandstone, generally coarse-grained and non-calcareous, with a few thin apple-green mudstones and mud-flake conglomerates. The top 12 ft (3.7 m) are finer-grained and more like overlying sandstone beds, but the top contact is sharp.

In the Tynagh area at least 620 ft (189 m)(base faulted) of very varied Red Beds lie between Lower Palaeozoics and Basal Sandstone in BH-443, drilled c.4 miles (6.4 km) west of the mine. BH-415 in the same area penetrated a full thickness of c.210 ft (64 m) of Basal Sandstone above Red Beds, though the contact may not be at the same horizon in the two holes. The Old Red Sandstone is clearly much thicker than at Silvermines (see also isopach map, fig. 2, in Emo and Grennan, 1982). The Basal Sandstone in BH-415 includes two atypical units of siltstone 21 ft (6.4 m) and 35 ft (10.6 m) thick, c.50 ft (15 m) and 150 ft (45 m) below the top, the lower one dark green.

Atypical interbeds nearer the top of the Basal Sandstone may be vestiges of the Mellon House Beds, a unit not otherwise represented in the Tynagh area. Skeletal and intraclastic calcarenites up to 18 ins. (45 cm) thick, and dark silty shale beds are quite common in the top 20 ft (6 m) of the Basal Sandstone in BH-178 (figs. 3 & 4) and other mine-area holes. The contact between Basal Sandstone and overlying Ringmoylan Shales is usually sharp here.

At Templemore hole 82-2 includes c.120 ft (36.5 m) of Basal Sandstone, sharply overlying red siltstone. The top of the sandstone (599 ft) is faulted. The unit includes rare black mudstone beds.

20-30 ft (6-9 m) of pale sandstone of similar character was penetrated in the Loughrea, Cloghan and Borris holes without reaching red beds. In the Rosenallis core N-1 a fault appears to have cut out the expected pale sandstone and part of the red beds sequence. However, it is possible that Basal Sandstone was not deposited here, as in the eastern part of the North Midlands Province.

4.3 Mellon House Beds

Shephard-Thorn (1963, p.270) included c.40 ft (12 m) of sandy shale, siltstone, calcareous sandstone and thin limestones within the Mellon House Beds, but similar lithologies were also placed by him in the upper part of the Old Red Sandstone. The presence of Modiola seems to have been his criterion for the higher unit. However, in this paper all the transitional beds between the Basal Sandstone and the Ringmoylan Shales are regarded as Mellon House Beds. The bottom contact can be gradational; the top contact with the overlying black shales is sharp across most of the Limerick Province. The Mellon House Beds are over 125 ft (38 m) thick in north Co. Limerick.

A very distinctive unit occurs at the top of the Mellon House Beds in the central part of the Limerick Province. It consists of a variable sequence of very finely banded and laminated, siltstone, shale and limestone, locally mudcracked and possibly stromatolitic. The unit is 30 ft (9 m) thick in north Co. Limerick. It was first recognized at Gortdrum Mine (Thompson, 1967; 24 ft, 7.3 m thick) and named "Laminated Shales" by Steed and Tyler (1979). It extends into the Symposium area at Silvermines, but dies out further north.

The Mellon House Beds in V.40 at Silvermines consist of a 21-ft (6.4-m) sequence (864-885 ft) of units up to 2 ft (60 cm) thick of very finely interlaminated shale, siltstone and limestone, interbedded with sandy mudstones up to 3 ft (1 m) thick, which may be their bioturbated equivalent. The whole of this is Laminated Shales facies; no other Mellon House Beds are present. At Tynagh, Loughrea and Cloghan Mellon House Beds are absent, but may be represented by silty and skeletal interbeds in the upper part of the Basal Sandstone (see above).

At Templemore over 32 ft (9.8 m) of Mellon House Beds have a sharp contact with Ringmoylan Shales at 398 ft in hole 81-5. The top 10 ft (3 m) includes two very finely laminated beds, probably representing the Laminated Shales. These are underlain by 7 ft, 2.1 m (408-415 ft) of greenish silty mudstone, and over 15 ft, 4.5 m (T.D. 430 ft) of pink and green finely laminated sandstone with a diagenetically brecciated top and 1-ft (30 cm) bed of black shale. The contact with underlying Basal Sandstone is not represented in any of the Templemore cores.

In the Borris hole c.6 ft (1.8 m) of transitional lithologies, possibly Mellon House Beds, including thin calcarenites, lie between the Basal Sandstone and a fault of unknown throw at 1305 ft. At Rosenallis this part of the succession is faulted out.

The Mellon House Beds in the Symposium holes are poorly represented compared with north Co. Limerick. At Silvermines they are no more than one-fifth as thick and belong exclusively to the highest sub-unit, the Laminated Shales. North and east of Silvermines the Mellon House Beds are thinner or absent in Symposium holes. Northwards they have probably passed into the diachronous Basal Sandstone.

4.4 Ringmoylan Shales, Ferbane Mudstone and Ballyvergin Shale

4.4.a Definitions.--- The Ringmoylan Shales consist of thinly bedded fossiliferous shale and limestone with scattered thin siltstone bands. The contact with the underlying Mellon House Beds is very sharp at the top of the Laminated Shales. The top contact is less clearly defined. It is not exposed in the Ringmoylan Quay section in the type area in north Co. Limerick. Shephard-Thorn (1963) included all the shaly beds there in the one formation, estimated a total thickness of 200 ft (61 m), and listed Syringopora from the youngest beds. In cores from north Co. Limerick this coral is quite common in the shaly limestone above the Ballyvergin Shale, but is seldom, if ever, present below it. Shephard-Thorn evidently included beds above the Ballyvergin in the Ringmoylan Shales.

It is apparent now that in different parts of the Limerick Province shaly beds extend upwards to different levels above the Ballyvergin marker, before being replaced by cleaner, thicker-bedded limestone. (Further south the contact is below the Ballyvergin.) The contact is often gradational and therefore difficult to place. In this paper (and Bruck 1982) the top of the Ringmoylan Shales is placed at the sharp base of the Ballyvergin Shale, but it is stressed that in the northern half of the Limerick Province beds immediately above the Ballyvergin (i.e. bottom part of the Lower Ballysteen Limestone) are of Ringmoylan Shales facies. In north Co. Limerick the Ringmoylan Shales, thus defined, are c.150 ft (45 m) thick.

The Ballyvergin Shale (Hudson and Sevastopulo, 1966, p.290, unit 197-217 ft; Clayton et al., 1980) is a green-grey, non-calcareous mudstone with thin interlaminated siltstone bands. Top and bottom contacts are very sharp. It is believed to be a synchronous unit, representing a unique and short-lived depositional event unrelated to vulcanism. The Ballyvergin is particularly important as a widespread marker in south-west Ireland, as it occurs within various clean and shaly limestone sequences, and proves their diachronous relationships.

In the north-eastern extremity of the Limerick Province and beyond, the Ballyvergin Shale is no longer recognizable in core; it appears to have passed laterally into normal dark grey shales within a thick sequence of Ringmoylan Shales type. The term 'Ferbane Mudstone' has previously been used for this sequence in the area of the Ferbane and Moate Inliers. It is retained in this paper for the shaly successions in which the Ballyvergin is absent.

4.4.b.Ringmoylan Shales.--- At Silvermines the Laminated Shale in V.40 is overlain by 68 ft, 20.7 m, (796-864 ft) of Ringmoylan Shales, consisting mainly of thin-bedded shale and limestone with minor siltstone. The bottom 8 ft (2.4 m) includes thin sandstones and biosparites with haematite grains. (Haematitic calcarenite occurs widely at the base of the Ringmoylan Shales.) Immediately above this is a distinct 15 ft (4.5 m) unit (841-856 ft) of non-calcareous black shale with very minor siltstone and calcarenite. The black shale is a widespread unit within the Ringmoylan Shales north and east of Silvermines, though absent in the type area. Beds above the Ballyvergin in V.40 are much less shaly, so at Silvermines there is close coincidence between the Ballyvergin and the top of the Ringmoylan shales facies.

The Ballyvergin Shale is 11 ft (3.3 m) thick in V.40 (785-796 ft), where it appears to be complete. A high proportion of Silvermines cores through the Ballyvergin show veining or obvious faulting, and it is difficult to establish whether the unit really varies in original thickness here, and if so what the pattern is.

At Templemore the Ringmoylan Shales (308-398 ft in 81-5) are generally similar to Silvermines, though thicker by 22 ft (6.7 m). The top 15 ft (4.5 m) is lithologically similar to beds above the Ballyvergin. Very little skeletal debris is present in the bottom 35 ft (10.6 m) of the Ringmoylan Shales here, except in the basal 2 ft (60 cm), which includes intraclastic calcarenite. In the Borris hole a 40-ft (12.2-m) section of Ringmoylan Shales overlies the fault at 1305 ft in B-2. The top contact is probably faulted also. No Ballyvergin is recognizable.

At Tynagh Ringmoylan Shales lie directly on the Basal Sandstone with practically no transition. In BH-178 c.5 ft (1.5 m) of almost pure black shale overlies the contact (1636 ft). A shale-dominant succession 116 ft (35.4 m) thick (top at 1520 ft) consisting mainly of thin-bedded shale and limestone with bands of finely laminated calcareous siltstone, overlies the sandstone. The Ballyvergin Shale, 11 ft (3.3 m) thick, lies in the middle of it (1575-1586 ft) and does not coincide with any significant lithological change. On the present definition, however, the top 55 ft (16.7 m) is placed within the Lower Ballysteen Limestone. The top 12 ft (3.6 m) of the shale sequence (1520-1532 ft) consists of uniform black shale with rare limestone and siltstone bands. It is a distinct, correlatable unit, lithologically similar to thick interbeds in the upper half of the Lower Ballysteen Limestone.

The Loughrea succession is very similar with slight thickness differences. The shaly sequence is 103 ft (31.4 m) thick (LA-3, 878-981 ft); the Ballyvergin (924-934 ft) is 10 ft (3 m) thick and lies in the middle of it. (The change in shale-percent symbol relative to Tynagh in figure 4 is not very significant; the cores have not been compared directly.)

4.4.c. Ferbane Mudstone. --- At Cloghan the shaly sequence (BR-1, 1362-1525 ft), here Ferbane Mudstone, is 47 ft (14.3 m) thicker than at Tynagh and there is no Ballyvergin Shale. Apart from poor recovery between 1422 and 1432 ft, there is no sign of faulting in the core, and the Ballyvergin has probably passed laterally into black shale, losing its distinctive green colour. A three-part division of the Ferbane Mudstone is discernible.

The lower half of the Ferbane Mudstone in BR-1 (1436-1525 ft) consists mainly of dark, non-calcareous shale with varying, minor proportions of finely laminated calcareous siltstone in bands rarely more than 1 in (2.5 cm) thick. Thin calcarenites are very much sparser than at Tynagh below the Ballyvergin, and are absent in some intervals up to 20 ft (6 m) thick. Scattered sandstones up to 4 ins (10 cm) thick are present in the bottom few feet. In the top 9 ft (2.7 m) (1436-1445 ft) shale is subordinate to calcareous siltstone, which is locally burrowed. The lower half of the Ferbane Mudstone thus resembles the bottom part of the Ringmoylan Shales at Silvermines (V.40, below 841 ft) and Templemore (81-5, below 360 ft), but is 3 or 4 times as thick.

In the middle part of the Ferbane Mudstone (BR-1, 1402-1436 ft) shelly argillaceous calcarenites, locally up to 1 ft (30 cm) thick, are much commoner, but remain subordinate to shale with siltstone bands. The upper part of the Ferbane Mudstone (above 1402 ft) is a 40-ft (12.2-m) dark grey, non-calcareous shale almost entirely devoid of siltstone bands except in the top 7 ft (2.1 m). It includes a few thin shelly calcarenites, but is otherwise without limestone or visible skeletal debris. This shale is similar to the 12-ft (3.6-m) shale at the top of the Ringmoylan Shales facies at Tynagh (BH-178, 1520-1532 ft) and probably correlates. If so, the top contact of the Ferbane Mudstone is laterally equivalent to a horizon near the middle of the Lower Ballysteen Limestone. The Ballyvergin horizon would belong somewhere between 1402 and 1436 ft in BR-1 according to these correlations.

In the Rosenallis cores the Ferbane Mudstone shows a somewhat similar 3-part division (shale on top with rare interbeds; shale with limestone; shale with siltstone) as at Cloghan, but the total thickness is considerably greater and there are some minor lithological changes. In D-1 a fault of unknown throw at 146.4 m occurs close to the transitional top. Steep dips and possible subsidiary faults affect various parts of the section below, but marker beds near the bottom of this core clearly trace across to the top of N-1, which is little disturbed down to the fault at 71.8 m. The succession was not logged in detail. Comparison with the Borris succession is hindered by probable faults in B-2, but there appears to be a very marked decrease in thickness and increase in the amount of calcarenite southwards from Rosenallis (fig. 4).

The Ferbane Mudstone extends to the north side of the Moate Inlier, still in the same 3-part form; the Moyvore drilling to date has not ruled out its presence there also (p.13).

4.4.d. Summary.--- The upper part of the Ringmoylan Shales facies shows clear diachronous relationships in the Symposium area. At Silvermines the top of the unit coincides with the Ballyvergin Shale. To the north at Tynagh the Ballyvergin occurs 55 ft (16.7 m) below the top of the shale facies; i.e. about half way up the Lower Ballysteen Limestone. Further east at Cloghan and Rosenallis the Ballyvergin is absent, but correlations of the top shale bed suggests that the top of the shaly sequence is at the same stratigraphic level as at Tynagh.

The thickness of the Ringmoylan Shales facies nearly doubles from Silvermines (68 ft, 20.7 m) to Tynagh entirely by the addition of beds above the Ballyvergin. There is a further thickness increase towards Cloghan (163 ft, 49.7 m) and again towards Rosenallis (c.240 ft, 73 m), but it is not at present clear whether this is due to local downwarp or to facies change in the bottom part of the section. The thickness reduction between Rosenallis and Borris is even more pronounced, if the incomplete successions are correctly interpreted in figure 4.

4.5 Lower Ballysteen Limestone

Shephard-Thorn (1963) did not subdivide the Ballysteen Limestone, but subsequent drilling has shown that the lower part can be readily distinguished throughout most of the Limerick Province as the "Lower Ballysteen Limestone". The top contact of this is placed at a distinct lithological change some 10-30 ft (3-9 m) below the Fine Calcarenite Marker, varying with the location. The base is taken at the top of the Ballyvergin Shale, where present, but because of large-scale diachronism the lower part of the unit is of Ringmoylan Shales facies in some areas. Exceptionally good stratigraphic control on the Lower Ballysteen Limestone is provided by the Ballyvergin Shale and the Fine Calcarenite Marker.

At Silvermines the Ballyvergin in V.40 is overlain by 118 ft, 36 m (667-785 ft) of varied, thin-bedded, commonly nodular limestone with subordinate shale, constituting the Lower Ballysteen Limestone. Syringopora is common in the lower half. The top contact, 12 ft (3.6 m) below the Fine Calcarenite Marker, is sharp at an upward change into more uniformly argillaceous limestone.

The Lower Ballysteen at Templemore is generally similar to Silvermines. The thickness in 81-5 (c.95 ft, 29 m) may have been slightly reduced by faulting. Near the middle of the unit is a 10-ft (3.1-m) black, unfossiliferous shale (228-238 ft) with rare thin siltstone bands; its base is faulted.

In the Borris hole neither the Ballyvergin Shale nor the Fine Calcarenite Marker are recognizable, but nodular-bedded limestone and shale similar to the Lower Ballysteen elsewhere are present from c.1156 ft down to the probable fault at 1265 ft. This sequence includes six shales 3-7 ft (1-2 m) thick with thin siltstone bands and little or no skeletal debris, similar to the 10-ft (3-m) bed in the Templemore section. The shale-dominant succession below 1265 ft is of Ringmoylan Shales facies, but could belong above the Ballyvergin horizon. The absence of the Ballyvergin could be due to faulting at 1265 ft or to lateral passage into the black shales. A 14-ft (4.3-m) gap in the section below 1206 ft is due to lack of recovery.

At Tynagh the lower half of the Lower Ballysteen Limestone is represented by Ringmoylan Shales facies (1520-1575 ft in BH-178; see above). The upper half (1452-1520 ft; 68 ft, 20.7 m thick) consists mainly of thicker-bedded calcarenite and subordinate thin shales. Several black shales 2 ft (60 cm) thick or more contain a few thin bands of siltstone and fine calcarenite. A 4-ft (1.2-m) shale of similar type forms the top bed in the Lower Ballysteen in BH-178. The 12-ft (3.7-m) shale bed at the top of the Ringmoylan Shales facies (1520-1532 ft) is also of this type.

An important local marker, the Tynagh Sandy Band, lies c.10 ft (3 m) above the 12-ft shale. In BH-178 it is 10 ft (3 m) thick (1500-1510 ft) and consists of alternating fine- to medium-grained, locally laminated, sandstone, and dark, very fine silty sandstone with burrows. The Tynagh Sandy Band increases in thickness north-eastwards to at least 45 ft (13.7 m) 2.5 mls (4 km) from the mine (BH-179), and becomes more uniform; it thins southwards to 3 ft (1 m) or less 2 mls (3.2 km) south-west of the mine (BH-169).

At Loughrea the Lower Ballysteen succession (LA-3 826-924 ft) is broadly similar to Tynagh, but slightly thinner (98 v.123 ft, 29.8 v. 37.5 m) and with some lithological changes. The Ringmoylan Shales facies above the Ballyvergin is 9 ft (2.7 m) thinner (46 ft, 14 m), but again has the unfossiliferous shale at the top, here 6 ft (1.8 m) thick. This shale is overlain directly by a thickened-up Tynagh Sandy Band (28 ft, 8.5 m thick; 850-878 ft), made up as follows:

Top: 14 ft (4.3 m)	Light grey, weakly calcareous, fine sandstone, locally silty and burrowed, locally finely laminated
11 ft (3.4 m)	Interbedded similar sandstone and subordinate dark siltstone, partly burrowed, with rare brachiopods.
3 ft (90 cm)	Brachiopod-rich calcarenite with sandstone and siltstone as above.

The 24 ft (7.3 m) of beds above the Tynagh Sandy Band consist mainly of brachiopod-rich, fine calcarenite and interbedded silty shale. A 5-ft (1.2-m) siltstone-banded black shale at the top probably correlates with the top bed in the Lower Ballysteen at Tynagh.

4.6 Cloghan Sandstone

4.6.a. Successions.--- At Cloghan the Ferbane Mudstone is overlain by a varied sandstone and siltstone sequence 105 ft (32 m) thick (BR-1, 1257-1362 ft), termed here the "Cloghan Sandstone". The base is gradational through a few feet into the underlying shale. The top contact is a very sharp, undulatory, stylolitic surface, overlain by a limestone succession of Middle Ballysteen type.

The bottom 32 ft (9.7 m) of the Cloghan Sandstone in BR-1 (1330-1362 ft) is a transitional unit, consisting mainly of heterolithic calcareous siltstone and dark silty shale, with a few thin calcarenites and local burrowing. These beds only differ from the Ferbane Mudstone below 1445 ft in having a higher proportion of siltstone. The rest of the Cloghan Sandstone is a varied sequence dominated by calcareous, fine to medium-grained sandstone with thin biosparites common in the upper half. A few siltstone-banded shales up to 3 ft (1 m) thick are also present, and two beds of uniform coarse-grained sandstone 7-8 ft (c.2.3 m) thick.

At Rosenallis a generally similar sandy succession, dominated by finely laminated calcareous siltstone and fine sandstone with scattered shelly biosparites, overlies the fault at 146.4 m in D-1, but it is at least 50 ft (15 m) thicker than at Cloghan. As at Cloghan the bottom part is mainly thinly banded calcareous siltstone and shale with a few sandstone beds up to 3 ft (1 m) thick. An unknown amount of section is faulted out at the base. The top contact is again very sharp, but unfaulted.

4.6.b Relationship with Lower Ballysteen Limestone.--- The Cloghan Sandstone is interpreted as laterally equivalent to the upper part of the Lower Ballysteen limestone at Tynagh, because of the probable correlations of over- and under-lying units. The upper part of the underlying Ferbane Mudstone is believed to be laterally equivalent to the lower part of the Lower Ballysteen Limestone (Ringmoylan Shales facies) at Tynagh (p.43 above), the distinctive black shale at the top of each correlating specifically. Immediately above the Cloghan Sandstone in BR-1 is limestone very similar to the bottom part of the Middle Ballysteen at Tynagh, though in BR-1 the Fine Calcarenite Marker is not recognizable. The Cloghan Sandstone appears therefore to be equivalent to the Tynagh Sandy Band, and to have thickened up at the expense of the limestone and shale above and immediately below that unit. Continuity between the two sand bodies is not necessarily implied, but the Tynagh Sandy Band does thicken more rapidly north-eastwards (BH-179) than towards Loughrea.

The Cloghan Sandstone evidently represents a major lobe of northerly derived sand with maximum thickness in the vicinity of Rosenallis. The sand spread south of the latitude of Tynagh; the relatively thin Tynagh Sandy Band may have been a marginal tongue of one part of it. The southern limit of the Cloghan Sandstone appears to be rather abrupt and to lie somewhere north of Borris-in-Ossory (map, fig. 1). Northwards it is a distinct unit on the north side of the Moate Inlier overlying Ferbane Mudstone. Further north it presumably merges with the Basal Sandstone of Keel, etc., as the Ferbane Mudstone wedges out (fig. 3).

4.7 Middle and Upper Ballysteen Limestones

4.7.a Introduction.--- Above the easily separable lower division the Ballysteen Limestone consists mainly of a thick succession of limestone units, which become increasingly argillaceous upwards. Middle and Upper divisions have been recognized (e.g. by Bruck, 1982), but the boundary between them is gradational and difficult to place consistently across the Limerick Province. The boundary will not be defined in this paper, but its approximate position is indicated for each succession. The Middle Ballysteen is characterized by relatively thick, uniform beds of argillaceous limestone with thin shale interbeds. The Upper Ballysteen is generally shalier and more varied. The top contact is the base of the reef, which can be gradational through tens of feet. The bottom contact of the Middle Ballysteen Limestone is generally sharp, lying 10-30 ft (3-9 m) below the Fine Calcarenite Marker, depending on locality. Lateral relationships above the Fine Calcarenite Marker are generally much less clear than those below, as extensive markers have not been identified, and lithological differences between units are often subtle. The total thickness of the Middle and Upper Ballysteen is several times greater than that of the combined underlying carbonate units.

The Fine Calcarenite Marker is a relatively clean, uniform calcarenite with wispy shale partings and gradational top and bottom. It is a widespread, easily recognizable marker, known in cores from as far apart at Tynagh, Templemore, Gortdrum and Kerry Head. Near Gortdrum it is exposed in the quarry at Oola. Parallelism between this marker and shale beds below suggests that it is a synchronous unit.

4.7.b Normal successions.--- At Silvermines the Lower Ballysteen is succeeded in V.40 by 355 ft (108 m) of rather uniform argillaceous calcarenite (312-667 ft), most of it rich in brachiopods. The base of this unit, 12 ft (3.7 m) below the Fine Calcarenite Marker (633-655 ft), is fairly sharp at the top of the shaly interbeds typical of the underlying sequence. The uppermost 50 ft (15 m) shows transitional features into the slightly shalier overlying unit. The top is placed at 312 ft at the lowest distinct black unfossiliferous shale (8 ins, 20 cm thick here), which is characteristic of the next 36 ft (11 m) of section (276-312 ft). 312 ft could be taken as the base of the Upper Ballysteen, but further small increases in shale content occur at, or close to, unit boundaries at 276 and 213 ft. These units are based partly on bedding characteristics, which should also be considered in any formal definition of the Middle/Upper Ballysteen boundary. Different features change at different levels.

Above 312 ft the succession is more varied. Upwards in successive units limestones become more argillaceous and shales become thicker and commoner to a maximum in V.40 betweeen 137 and 213 ft. V.40 includes several faults above 150 ft, though by comparison with V.25 little of the shaliest unit has been cut out. The detailed succession above this unit was not established, but the shale content decreases again. V.25 and V.40 together indicate that above the shaliest unit there are some 50-70 ft (15-20 m) of interbedded limestones and shales, which are in turn overlain by thinly nodular-bedded cherty limestone with shale partings, typical of the reef-base transition throughout most of the Limerick Province.

At Tynagh above the 5-ft (1.5-m) black shale at the top of the Lower Ballysteen in BH-178 (1452 ft) the succession for c.430 ft (131 m) consists mainly of argillaceous crinoidal limestone with thin shales. There are minor variations, but the succession is divisible principally on the basis of the following markers (see Tynagh column, fig. 4):

1. 1041-1045 ft (4 ft,1.2 m)	"Ten-forty-five (1045) Marker". Dark grey shale bed with scattered thin siltstone bands. Often with one or two thinner similar beds in underlying 10 ft (3 m).
2. c.1196-1228 ft (c.32 ft,10 m)	"Silty Shale/Biosparite Unit". Mainly silty calcarenite, with relatively common beds of coated-grain biosparite, and distinctive black shale, barely fossiliferous, with siltstone bands, in scattered beds up to 2 ft (60 cm) thick. Top and bottom boundaries gradational.
3. 1290-1300 ft (13 ft,3.9 m)	"Medium Calcarenite Marker". Uniform medium-grained crinoidal calcarenite with common brachiopods. Not distinct in all cores.
4. 1414-1434 ft (20 ft,6.1 m)	"Fine Calcarenite Marker". As for Silvermines. Lies 19 ft (5.8 m) above the Lower Ballysteen in BH-178.

The equivalent of the Silty Shale/Biosparite Unit in BH-179, 2.5 miles (4 km) north-east of the mine, includes one fine-grained calcareous sandstone bed 6 ft (1.8 m) thick (2008-2014 ft), which may relate to the Loughrea succession (see below). The 1045 Marker may be recognizable beyond the Tynagh area, as it is exceptionally thick and isolated. In BH-179 the marker consists of a group of shale beds 4-7 ft (1.2-2.1 m) thick through 20 ft (6 m) of section.

Above c.1020 ft in BH-178 there is a slight shale increase comparable with that at 312 ft in V.40. In both cases the overlying unit contains Syringopora; at Tynagh the coral is so characteristic that these beds have been called the "Syringopora Unit" (BH-178, 879-1041 ft), the base being placed for convenience at the 1045 Marker. A more important lithological break occurs at the top of the Syringopora Unit, and would be a more suitable base for the Upper Ballysteen Limestone.

The overlying unit (782-879 ft) consists of interbedded shale and very fine, burrowed, siliceous, nodular calcarenite. Crinoid debris is much sparser than in underlying beds. The shale is very calcareous and irregularly banded with very fine skeletal debris. The silica seems to be an incipient form of chert rather than detrital quartz grains; chert is developed in this unit in some cores (e.g. BH-426, 190-330 ft). This distinctive facies is not present in V.40.

The base of the overlying unit in BH-178 (682-782 ft) is sharply defined by a 2-ft (60-cm) coarse crinoidal calcarenite. In some holes the contact is less distinct. The unit consists mainly of nodular-bedded, light grey micrite with subordinate shale interbeds and uncommon crinoid debris. Burrowing is much rarer than below.

Above 682 ft is a varied, shale-dominant succession c.180 ft (55 m) thick, consisting of shale with common fenestrate bryozoa and bands of large crinoid ossicles, and subordinate interbeds of crinoidal limestone. This looks like a reef-equivalent facies, but it is older than the reef in the mine area. Between c.500 ft and the reef base at 432 ft the proportion of shale decreases and the succession goes up through c.70 ft (21 m) of the reef-base transition beds. The lower part consists of thin-bedded, very coarse crinoidal calcarenite. This grades up into more variable crinoidal limestone, locally conglomeratic, with minor shale interbeds.

In contrast to Silvermines and most of the Limerick Province, there is no sub-reef chert sequence in BH-178 or most other mine area cores, though chert is common in reef-equivalent beds in the basin to the north, and immediately above the reef. Its absence below the reef may be linked with the marked variability of the reef-base transition here and the possibility that the Tynagh reef started growth somewhat later (p.54).

The reef in BH-178 is mainly a conglomeratic facies, locally pink, and is much thinner (c.100 ft, 30 m) than in the mine itself (500 ft +, 150 m) c.1/4 mile to the south (see cross-sections in Derry, et al., 1965, fig.2; or Schulz, 1966, fig.3). Red ironstones (Schulz, 1966) are interbedded with reefal beds between c.325 and 380 ft, and also below the reef at 479-483 ft. A tuff 1 ft (30 cm) thick lies c.40 ft (12 m) above the reef at 279 ft.

Compared with Silvermines, the Middle and Upper Ballysteen Limestone at Tynagh are together much thicker: c.1020 ft v. c.650 ft (311 m v. 198 m) and the Upper Ballysteen is substantially different. There is general lithological correlations of the two successions up to 879 ft in BH-178 and 213 ft in V.40 (fig. 4). These levels may not be time-equivalent, but the main thickness difference appears to be in the upper half of the Ballysteen Limestone.

4.7.c Peripheral Ballysteen Successions.--- Of the various abnormal successions on the periphery of the Limerick Province, Cloghan is the least modified in the Middle and Upper Ballysteen Limestone. The contact with the Cloghan Sandstone is sharp at 1257 ft in BR-1. This contact is not necessarily exactly time-equivalent to the base of the Middle Ballysteen at Tynagh, but in both areas there is an abrupt reduction in the proportion of clastics immediately above. The Fine Calcarenite Marker is not recognizable in BR-1, but the uniform, medium-grained calcarenite beds in the bottom 50 ft (15 m) are closely similar to beds adjacent to the marker at Tynagh and Silvermines. The succession up to 705 ft is of much the same type as the Middle Ballysteen at Silvermines and Tynagh. It consists mainly of argillaceous crinoidal calcarenite with common brachiopods and very subordinate silty shale interbeds, with some variation.

There are some peculiarities within this succession. Between c.900 and 1100 ft coarse biosparite, often with thickly alga-coated shell debris, becomes common in beds up to 4 ft (1.2 m) thick, together with scattered oolite beds up to 1 ft (30 cm) thick. Within this interval, between c.970 and 1008 ft, there is a group of shale beds up to 5 ft (1.5 m) thick, each typically relatively pure at the bottom, with an increasing proportion of thin siltstones upwards, and with skeletal debris and bioturbation at the top. The shales are interbedded between argillaceous biomicrites and biosparites. A 10-ft (3-m) coarse-grained uniform oosparite lies immediately above (960-970 ft). The lithologies here suggest correlation with the Silty Shale-Biosparite Unit at Tynagh (fig. 3). The unit above this is distinctly siltier and burrowed (878-925 ft). There are two 5-6-ft (1.5-1.8-m) shale beds at 765-770 and 714-720 ft. These are black, calcareous, and include thin siltstone and calcarenite bands. A very tentative correlation of one or other of these could be made with the 1045 Marker at Tynagh (fig. 3). Similar scattered shale beds 3-5 ft (1-1.5 m) thick occur higher up between 611 and 665 ft.

Above 705 ft the shale content increases incrementally until it becomes predominant in mose units above 580 ft; and the distinction between shale and calcarenite becomes sharper. Shale beds are up to 3 ft (1 m) thick, very calcareous and fossiliferous. There is a gradual decline in the amount of crinoid debris above c.740 ft, and calcarenite is generally finer-grained. There is no natural break for the Middle/Upper Ballysteen boundary in this sequence; unit bases at 705 or 646 ft are possibilities.

There are some features in this part of the succession that are similar to Tynagh, suggesting tentative correlation. In addition to the general transition from Middle to Upper Ballysteen lithologies, the unit between 528 and 580 ft in BR-1 contains Syringopora colonies, though it is shalier than the Syringopora Unit at Tynagh. In both successions there is a sharp increase in the amount of shale immediately above. In BR-1 the unit at 476-528 ft is dominated by dark grey calcareous shales up to 5 ft (1.5 m) thick, banded with skeletal debris and uncommon siltstones less than 1/4 in (6 mm) thick; argillaceous calcarenite interbeds are very subordinate. The shales are similar to those below, but commoner. (The lithology is also very similar to some of the Ringmoylan Shales, as shown by direct comparison of cores.) In contrast to the shaly unit at Tynagh just above the Syringopora Unit, this BR-1 unit lacks the fine siliceous calcarenite.

Above 476 ft is a similar but less shaly unit up to 373 ft. This is overlain by 32 ft (9.7 m) (341-373 ft) of nodular fine calcarenite interbedded with subordinate shale. Shale increases incrementally above this, to become predominant again above 280 ft, and is accompanied by a gradual, but marked, reduction in skeletal debris. Caninia is present between 210 and 280 ft. An upper shale unit 54 ft (16.4 m) thick (156-210 ft) consists of dark grey calcareous shale with rare limesotne nodules, scattered zaphrentids and very thin bands of fine skeletal debris. It is much less fossiliferous and silt-banded than the shale unit at 476-528 ft.

Above 156 ft shale decreases and there is a fairly standard cherty transition towards the reef. Core above 120 ft was not available; company logs suggest an exceptionally thick sequence of thinly bedded reef limestone somewhere above 120 ft, overlain above c.80 ft by normal Waulsortian.

The succession within the Ballysteen Limestone in BR-1 shows general similarity to the Middle and Upper Ballysteen at Tynagh. It is slightly thicker, includes more siltstone in the lower two-thirds, and has a 10-ft (3 m) oolite with no counterpart in BH-178. Although Tynagh also has a thick shale sequence below the reef (BH-178, 432-682 ft), this shale differs from BR-1 in not showing the regular upwards decrease in carbonates and skeletal debris. At Tynagh scattered micrites and coarse crinoidal bands suggestive of reef-equivalence dilute the upper shale unit.

The incomplete succession at Rosenallis above the Cloghan Sandstone consists of fairly typical Middle Ballysteen Limestone, except for an oolite unit over 50 ft (15 m) thick at the base, which is not represented at either Cloghan or Borris. The base of the oolite (90.7 m in D-1) is very sharp, but unfaulted. The unit consists of massive-bedded, coarse oosparite with some banded biosparite. The top contact is faulted, cutting out an unknown amount of section (there is little deformation here).

Above the fault the succession in D-1 consists mainly of nodular bedded, slightly argillaceous calcarenite with very subordinate diffuse shale interbeds. Brachiopods are common. There is some variation, including a cleaner, coarser-grain calcarenite unit (31.5-40.8 m; c.30 ft (9 m) true thickness) much thicker than similar beds above and below. At 51.8 m is an atypical pale calcareous siltstone c.1 ft (30 cm) thick with irregular bands of silty shale. Thick colonies of encrusting bryozoa are present at 42.9 m and common at the top of the core. Similar bryozoa are also a feature of part of the Borris succession, and suggest possible correlation of the top of D-1 with approximately the 700 ft level in B-2.

The Middle and Upper Ballysteen succession at Loughrea, (fig 4), though much closer to Tynagh geographically than to Cloghan, shows much greater stratigraphic difference. It is about half as thick, and includes thick sandstone and oolite beds in the lower half. The base of the Middle Ballysteen is placed, as at Tynagh, at the top of the highest black shale typical of the underlying sequence (LA-3, 826-ft). The Fine Calcarenite Marker is represented, presumably, by a 9-ft (2.7-m) coarse oosparite (808-817 ft), 9-ft (2.7-m) above the contact. It lies within a 36-ft (11-m) limestone unit similar to corresponding beds at Tynagh, with a faulted top at 790 ft. The succession above this up to 631 ft, summarized in the table below, is not of Ballysteen facies.

631-645 ft	14 ft, 4.2 m	Sandstone, fine grained, light grey, locally calcareous, mainly massive.
645-651 ft	6 ft, 1.8 m	Siltstone, bioturbated, light and dark, with rare black shale interbeds.
651-671 ft	20 ft, 6.1 m	Mainly biosparite, medium to coarse, coated-grain, locally with thick-shelled brachiopods; minor silty shale interbeds. In top 4 ft, 1.2 m grades up through skeletal shale into pure black non-calcareous shale.
671-690 ft	19 ft, 5.7 m	Interbedded coarse biosparite, fine oosparite and fine calcareous sandstone in bottom 8 ft, 2.4 m; overlain by 5 ft, 1.5 m of bioturbated light and dark banded siltstone; overlain by 6 ft, 1.8 m of fine sandstone, mainly non-calcareous. Base faulted.
690-695 ft	5 ft, 1.5 m	Argillaceous crinoidal calcarenite with minor biosparite; 1 ft, 30 cm of shale with nodular micrite.
695-736 ft	41 ft, 12.5 m	Mainly fine and medium-grained oosparite in beds up to 14 ft, 4.2 m thick, with subordinate interbeds of fine calcareous sandstone and minor silty shale.
736-790 ft	54 ft, 16.4 m	Fairly uniform thinly interbedded, burrowed siltstone, crinoidal calcarenite, fine calcareous sandstone and shelly biosparite. Base faulted.

The lowest unit is probably that represented by large blocks at surface 1 1/2 miles (2.4 km) W.N.W. of Loughrea, originally mapped as a basal sandstone inlier by the Geological Survey. The top three units (40 ft, 12.2 m thick) appear to constitute a single cyclic sequence. The 19 ft, 5.7 m of the beds below this combine as a similar sequence.

This succession (631-790 ft; 159 ft, 48.4 m thick) is of Pale Beds type, but a direct connection with the North Midlands Province cannot be established from presently released cores. Correlation with Tynagh is uncertain, but the oolites and sandstones may be equivalent to the Silty Shale-Biosparite Unit (fig. 4). The 14-ft (4.3-m) sandstone at 631-645 ft in LA-3 might possibly correlate with the sandstone in BH-179 at 2008-2014 ft, which is within this unit (p.49). Faults at 690 and 790 ft are small, as the main units in the succession can be matched in another core.

The succession between 416 and 631 ft is again of Middle Ballysteen type though distinctly less argillaceous than at Tynagh. Syringopora colonies between 435 and 450 ft and a unique 6-ins (15-cm) black shale at 478 ft suggest possible correlation with the Syringopora Unit and 1045 Marker. There are faults at 416 and 580 ft, probably not large. The lowest possible level for the base of the Upper Ballysteen Limestone is at 416 ft.

Above 416 ft the shale content increases in stages, mainly as subordinate interbeds of very calcareous, dull grey shale with scattered fine skeletal debris including zaphrentids. In contrast to Tynagh and elsewhere, there is no thick, shale-dominant sequence below the reef here; the shaliest unit (320-367 ft; 47 ft, 14.3 m thick), which grades up into typical sub-reef chert above 320 ft, is roughly half-and-half very calcareous shale and fine-grained siliceous limestone with weak burrowing and rare crinoid debris. This lithology is rather similar to the Tynagh unit (BH-178, 782-879 ft) immediately above the Syringopora Unit. Correlation is possible in view of relationships suggested above for the underlying beds.

Whatever the precise correlation of these beds, the Upper Ballysteen Limestone is disproportionately thin at Loughrea (fig. 4). One interpretation is that the lower part of the overlying reef is laterally equivalent to a large part of the Upper Ballysteen at Tynagh. It was noted above (p.50) that some lithologies in BH-178 above 782 ft suggest reef-equivalence. However, better evidence is required to prove this relationship. Alternatively there is a very condensed succession just below the Loughrea reef. The same problem applies to the relationship between Tynagh and Silvermines in a less extreme form (fig. 4). The thickness of the Middle Ballysteen in all three successions is much the same.

Core above 300 ft in LA-3 was not available. Company logs place the reef base at 275 ft. The various faults seen in the core are believed to be small, because the outcrop width of sub-reef limestones gives a roughly similar total thickness to LA-3. The succession above c.550 ft in LA-3 has not been duplicated in core.

Very different peripheral modifications to the typical Ballysteen Limestone successions are revealed east of Silvermines by the Templemore and Borris cores. The complete succession has not been drilled in either area, but there is sufficient overlap to illustrate nearly all of a hypothetical combined succession. The two drilling areas are 11 miles (17.7 km) apart.

The lower part of the Middle Ballysteen Limestone in the Templemore area is of typical lithology and includes the Fine Calcarenite Marker (core 81-5, 155-182 ft). Only c.200 ft of section is represented in 81-5; 81-3 probably extends it a little higher.

At Borris a full Middle Ballysteen succession is present in B-2 (473-1156 ft). It is exceptionally thick (683 ft, 208 m) and mainly more uniform and more argillaceous that at Silvermines or Tynagh. The base is gradational c.10 ft (3 m) above the highest thick (4 ft, 1.2 m) shale typical of the Lower Ballysteen. No Fine Calcarenite Marker was recognized. The top is placed at the base of a less argillaceous limestone unit (436-473 ft) that is more like overlying cherty beds. The top 30 ft (9 m) of the Middle Ballysteen is a transitional sequence.

The main exceptional features in this succession are as follows. The interval 613-699 ft is less argillaceous than the rest and consists of several units:

15 ft, 4.6 m	(613-628 ft)	Argillaceous limestone without shale interbeds.
10 ft, 3 m	(628-638 ft)	Thinly nodular-bedded, very fine calcarenite with diffuse silty shale interbeds.
32 ft, 9.8 m	(638-670 ft)	Argillaceous limestone with common Syringopora.
29 ft, 8.8 m	(670-699 ft)	Argillaceous limestone with wavy shale partings; common encrusting bryozoa.

Encrusting bryozoa are also present at 733 ft. Another relatively clean medium-grained calcarenite at 817-832 ft (15 ft, 4.5 m thick) also contains Syringopora. A few distinctive beds 3-4 ft (1 m) thick, consisting of thinly bedded silty shale and calcarenite, are present lower down (e.g. at 865,906 and 1090 ft). Siltstone in both shale and calcarenite is commoner below c.700 ft. There is no indication from lithologies where the top contact of the Middle Ballysteen in B-2 (473 ft) fits in the Silvermines or Cloghan successions.

The succession above 473 ft in B-2 is dominated by oolite and burrowed or cherty calcarenite, less argillaceous than below. Below a thick oolite in the middle the succession is as follows:

21 ft, 6.4 m	(294-315 ft)	Mainly fine biosparite, locally oolitic, with subordinate argillaceous calcarenite.
47 ft, 14.3 m	(315-362 ft)	Varied calcarenite with chert, burrowing and finely laminated silty shale/calcarenite.
44 ft, 13.4 m	(362-406 ft)	Variable, nodular-bedded, fine argillaceous calcarenite, partly crinoidal, without shale interbeds; chiefly distinguished by burrowing.

10 ft, 3 m	(406-416 ft)	Fine oosparite.
20 ft, 6.1 m	(416-436 ft)	Very fine-grained limestone with chert. Interbeds 1-9 ins (2.5-23 cm) thick consist of very finely laminated shale and fine calcarenite with burrowing, locally sub-mm in scale and very regular. Gradational top.
37 ft, 11.2 m	(436-473 ft)	Thin-bedded nodular fine calcarenite and distinct, but very subordinate, shale interbeds.

Beds of the same general character, but not identical, are present at Templemore in 81-4 below 214 ft. The finely laminated limestone/silty shale that characterizes parts of this succession (especially 416-436 ft) is a very distinctive lithology, which is also widely distributed as a subsidiary component in the Kildare Province. It is indicated by the 3-barred symbol beside the columnar sections in figure 4.

Above 294 ft in B-2 is an oolite unit 137 ft (41.7 m) thick (top at 157 ft), consisting of pale grey bio-oosparite with a wide range of grain sizes and proportion of skeletal debris. The Templemore hole 81-4 has a thicker oolite (178 ft, 54.2 m; 36-214 ft) of the same rather mixed character including a few 2-ft (60-cm) beds of coarse crinoidal biosparite and some shelly calcarenite. There is very little section above the oolite in 81-4, so the correlation of the top contact with B-2 is uncertain.

Above the main oolite in B-2 the succession is as follows:

17 ft, 5.2 m	(20-37 ft)	Interbedded biomicrite and units of very argillaceous calcarenite and skeletal shale.
44 ft, 13.4 m	(37-81 ft)	Pale grey oolite, mainly massive-bedded bio-oosparite.
76 ft, 23 m	(81-157 ft)	Varied fine calcarenite, mainly biosparite, with thin shale interbeds and partings. Thin dark chert bands common in top 20 ft (6 m), rare below. Bands of large crinoid ossicles common.

The top unit appears to be of normal Ballysteen type. The contact at 37 ft with the upper oolite is presumably older than the succession in core 81-9 at Templemore, but the size of the stratigraphic gap in the drilled succession there is uncertain. Mapping suggests that it is less than 100 ft (30 m), but exposure is poor.

The whole of the Borris succession in B-2 from 37 to 473 ft, and its less complete equivalent in 81-4 at Templemore, is quite unlike Ballysteen Limestone, and evidently represents a thick tongue extending from another stratigraphic province.

The uppermost part of the sub-reef succession in the Templemore area is represented mainly in hole 81-9, complemented by 81-8, which extends it up into the reef. These cores were not logged in detail; they show a gradual upward change from argillaceous limestone and shale to a thick (150 ft, 45 m) shale sequence with little skeletal cebris, changing abruptly at the top into normal reef-base transition beds. The succession is like that at Cloghan from c.630 ft up, but lacks the limestone-rich units in the middle. Isolated shale beds near the bottom of 81-9 are comparable with those below 610 ft in BR-1, but may not correlate.

5. The Kildare Province

5.1 Introduction

A succession quite distinct from those in the Limerick and North Midlands Provinces is present in the Boston Hill area of Co. Kildare. It is characterized by a more elaborate succession; by common beds of finely interlaminated calcareous siltstone and silty limestone (generalized barred symbol in figure 4); and by a thick (500 ft+, 150 m) crinoidal dolomite unit at the top. The succession is considerably thicker than in other Symposium cores. No Waulsortian reef is present in the Boston Hill cores. Reefs appear to be discontinuous in the area and either to overlie the Upper Dolomite or be laterally equivalent to the upper part of it. Although quite distinctive, the succession does have certain features in common with both the Limerick and North Midlands Provinces.

The extent of the stratigraphic province represented by the Boston Hill succession is poorly known. Correlatable units have been drilled at Monasterevin 9 miles (14.4 km) to the south-west, and at Betaghstown 10 miles (16.1 km) north-east. The drilling at Wheatfield, c.18 miles (29 km) E.N.E. of Boston Hill, has provided a composite section through mainly dolomitezed beds, some of which show strong lithological affinities with Boston Hill units. The succession there is much thinner, partly incomplete through faulting, and is difficult to correlate closely with Boston Hill. Nevertheless, it is evident that a generally similar succession is widespread in Co. Kildare and probably beyond, and that a distinct "Kildare Province" exists.

5.2 The Boston Hill Succession

5.2.a Introduction.--- Core 600/52 from Boston Hill, in combination with others (figure 4) gives a nearly complete succession from basal Red Beds up into the Upper Dolomite. The total thickness is c.3000 ft (915 m) from the top of 600/52. For convenience c.600 ft (180 m) of Upper Dolomite is omitted in figure 4 and a 450-ft (137-m) gap is left lower in the column. A number of faults cut 600/52, but comparison with adjacent holes has completed most of the succession. The summary below is based on reconnaissance logging.

5.2.b Red Beds, Lower Limestone Shales and Calcarenite "D". --- About 40 ft (12 m) of Red Beds at the bottom of 600/52 (2,318-2,362 ft) consist of red siltstone and laminate sandstone, grading down into pink, coarser massive sandstone with minor grey mudstone and scattered red to white quartz conglomerates up to 18 in (45 cm) thick.

Lower Limestone Shales sharply overlie the Red Beds in 600/52. Fine sandstone, alternating with sand-lensed mudstone, grades up into similar but less muddy beds in a sequence over 200 ft (60 m) thick (c.2110-2318 ft); the top contact is faulted. The upper part of the Lower Limestone Shales is present in 863/1 (995-1035 ft), but the sections probably do not overlap. The top 40 ft (12.2 m) consists of oolite and intrasparite with interlaminated shale and sandy limestone with minor burrowing. The total thickness of the Lower Limestone Shales probably exceeds 250 ft (76 m).

The overlying unit in 863/1 (941-995 ft), Calcarenite "D", consists of at least 50 ft (15 m) of varied calcarenite with minor shaly beds. Banded coarse intrasparite in the lower half is faulted at the top (972 ft). The upper half consists of varied biosparite, more uniform fine calcarenite, and thinly interbanded shale and limestone, again with a faulted top. Comparison with 600/52 suggests that these faults are small.

The succession from Red Beds to the top of Calcarenite "D", which is overlain by thick micrite, is generally similar to that at Sion Hill to the top of the Basal Transition Beds. It is also comparable with the Rosenallis succession to the top of the oolite. Whether or not these successions are exactly laterally equivalent, they all represent an initial transgressive sequence above basal Red Beds.

5.2.c Micrite Unit, Calcarenite "C", and Oolite Unit.--- A micrite unit 80-90 ft (24-27 m) thick overlies Calcarenite "D" in 863/1 (842-941 ft) with a faulted base. The micrite is mainly argillaceous and interbedded with calcareous shale and subordinate argillaceous calcarenite. Birdseye micrite is present locally in the unit in 600/52, which is very faulted.

A varied limestone succession c.200 ft (60 m) thick overlies the Micrite Unit in 863/1 (640-842 ft), and is distinguished from overlying beds, which include oolite, as Calcarenite "C". Three sub-units are recognized within it. The lower one (797-842 ft) consists of thinly bedded fine calcarenite with similar but more argillaceous interbeds; the top is gradational. The middle unit (725-797 ft) consists of argillaceous calcarenite rich in crinoids and brachiopods. Encrusting bryozoa are present near the top, which is sharp. The top unit (640-725 ft) consists of varied coarse calcarenite, including some oncholitic beds, alternating with laminated very fine calcarenite, though this is rarer in the bottom 25 ft (7.6 m).

The Oolite Unit overlying Calcarenite "C" in 863/1 is a mixed calcarenite sequence c.145 ft (44.2 m) thick (495-640 ft) with common oolite beds. It consists mainly of alternating crinoidal calcarenite, usually clean, up to c.20 ft (6 m) thick, and oolite beds up to c.7 ft (2 m) thick. Interbeds of laminated very fine calcarenite are present in the top 50 ft (15 m). The top contact is placed at the top of the highest oolite bed, but this is not otherwise a sharp break.

Correlation of the sequence from the micrite to the top of the oolite with units in other provinces is obscure in all but the most general terms. Some similarity with the Pale Beds is obvious, but the Micrite Unit is not necessarily the same age as in the North Midlands Province.

5.2.d Lower and Upper Laminated Limestone, Main Bioclastic Limestone and Calcarenite "B".--- Overlying the oolite in 863/1 the distinctive laminated silty limestone beds become much commoner in a unit c.80 ft (24 m) thick, the Lower Laminated Limestone. The top, placed at the highest of the common laminated beds, is faulted out in this hole at c.425 ft, but is present in 600/6, which did not reach the bottom. The unit consists of various calcarenite types, some fine-grained, and minor shale. The laminated beds, a subordinate component, are very fine silty calcarenites often with load-cast-like burrows. Lamination varies in thickness from c.0.5 to 5 mm, sometimes more.

The overlying Main Bioclastic Limestone is a monotonous succession of argillaceous calcarenites c.750 ft (228 m) thick (600/6 77-838 ft). Diffusely interbedded biomicrite and argillaceous crinoidal calcarenite are common. Very calcareous crinoidal shale is present only locally. Relatively clean calcarenite is predominant in the top 100 ft (30 m). About 100 ft (30 m) above the base one or two laminated limestone beds 3-6 ft (1-2 m) thick, similar to those below, are potential markers. The top contact is gradational over a few feet, as distinctly shaly interbeds become more common above.

The overlying Upper Laminated Limestone (c.320 ft, 97 m thick, but faulted; 600/52, 787-1110 ft) is also characterized by abundant laminated limestone beds. These are interbedded with a variety of other lithologies, including banded biosparite, stick-bryozoan biomicrite and burrowed fine silty calcarenite. Several marker beds are present, mainly distinctively laminated calcarenite and shale. A calcareous mudstone 8-10 ft (2.4-3 m) thick with scattered thin limestones occurs c.20 ft (6 m) above the base. A 1-ft (30-cm) black shale marks the top contact with the overlying clean calcarenite.

The overlying unit in 600/52 (35 ft, 10.6 m thick; 752-787 ft), Calcarenite "B", consists of thinly bedded very fine calcarenite with shaley and stylolitic partings. A few crinoidal calcarenite beds up to 2 ft (60 cm) thick are interbedded. The top contact is gradational into the overlying shaly sequence.

Correlation of the succession between the oolites and Calcarenite "B" is again very uncertain. The Main Bioclastic Limestone is somewhat similar to the Middle Ballysteen in the Borris succession. Both are overlain by varied calcarenites with the discinctive laminated limestone, suggesting possible correlation (fig. 4).

There is no representative of the Borris oolite at Boston Hill. No counterpart of the Lower Laminated Limestone was recognized at Borris. The Main Bioclastic Limestone is quite unlike any unit in the North Midlands succession. However, some lithologies in the Upper Laminated Limestone do resemble parts of the Shaly Pales; these include stick-bryozoan calcarenite and burrowed fine silty calcarenite.

5.2.e The Shaly Units.--- Over 300 ft (90 m) of varied shaly limestones overlie Calcarenite "B". Core 863/2 shows the most complete sequence, but the base is faulted. Equivalent beds in 600/52 are also faulted, so these cores provide no control on the amount of section missing in the bottom part. Three main shaly units have been distinguished.

The Banded Shaly Unit (863/2, 1000-1203 ft; over 180 ft, 55 m thick) consists typically of thinly banded shales in beds up to 5 ft (1.5 m) thick, and very fine, burrowed calcarenite, rarely crinoidal. The lower part is more calcareous, mainly burrowed silty calcarenite (600/52, 720-752 ft).

The Crinoidal Shaly Unit (863/2, 870-1000 ft; c.117 ft, 35.5 m thick) sharply overlies the lower and shalier unit. It consists of variably argillaceous thinly bedded fine calcarenite with shale interbeds and common nodular bedded crinoidal calcarenite. Burrowing is locally common.

The Dark Shaly Unit (600/52, 481-510 ft; 25-30 ft, 7.6-9 m thick) sharply overlies the previous unit, and is distinctly shalier. It includes common large crinoid ossicles up to 1/2 in (12 mm) across, and thin micrite beds. In 600/52 it is sharply overlain by the Upper Dolomite. In 863/2 it grades up at c.856 ft into limestone.

The shaly units show some similarities to the Upper Shaly Pales, such as silt-laminated shale, but correlation is extremely tenuous. The underlying Upper Laminated Limestone shows a slight resemblance to the Middle Shaly Pales.

5.2.f Calcarenite "A" and Upper Dolomite.--- Above the Dark Shaly Unit in 863/2 (682-856 ft) is a limestone unit c.150 ft (45 m) thick, Calcarenite "A". It consists mainly of fine-grained variably argillaceous calcarenite, locally crinoidal. The bottom of the unit, below a 20-ft (6-m) dolomite (base at 820 ft) includes biomicrite and chert.

The Upper Dolomite is over 500 ft (152 m) thick in 863/2. The lower part is massive-bedded and crinoidal. Some argillaceous dolomite is present above. Higher parts of the sequence are very brecciated. The bottom contact of the dolomite may be diachronous.

Correlation of this upper part of the succession is obscure. No other Symposium core has thick, mainly clean calcarenite sequence immediately below the reef. The relationship between the Upper Dolomite and reef in the area is not clear from these cores.

5.3 The Wheatfield Succession

The columnar section in figure 4 is simplified from a compilation by Drs. Strogen and Somerville (in press), based on at least 7 cores. Most beds are strongly dolomitized, but remnant textures are often clearly visible, and many potential marker beds are present. Tectonic veining and brecciation are quite common, but only the usual transitional succession between Red Beds and the carbonates is obviously not represented in core. Non-tectonic brecciation of presently unknown origin has affected much of the Cyclic Member and parts of other units, partly obscuring the succession and true thicknesses. The following summary and unit names are based mainly on notes supplied by Strogen and Somerville.

Overlying Lower Palaeozoics unconformably are about 100 ft (30 m) of Old Red Sandstone beds. These consist of interbedded red conglomerate, sandstone, and massive siltstone with caliche. The top 17 ft (5.2 m) includes black laminated and bioturbated interbeds, suggesting that it lies close below the expected Lower Limestone Shales. The top contact with the overlying dolomite is sharp; it shows little sign of disturbance, even though interpreted as a large fault.

After a presumed fault gap, the succession continues up into the Mixed Member, consisting of c.75 ft (23 m) of alternating fine crinoidal dolomite and streaky laminated dolomite. The basal part is a dolomicrite, which may correlate with the Micrite Unit exposed near Naas (Bruck, 1971), and the Boston Hill Micrite Unit. Streaky beds above the Mixed Member suggest correlation with the Lower Laminated Limestone of Boston Hill.

The overlying Cyclic Member, c.650 ft (198 m) thick, consists of thick sections (100 ft, 30 m+) of fine dolomite with scattered crinoid debris, and units of medium-grained crinoidal calcarenite locally over 40 ft (12 m) thick, not all dolomitized. Units up to 10 ft (3 m) thick of laminated fine silty dolomite, locally cross-bedded, are scattered through the Member, mainly in the upper half. Strogen and Somerville recognize 6 major cycles of alternating argillaceous biomicrite and crinoidal calcarenite with associated laminated beds. The thickness and uniformity of the main part of this unit suggest correlation with the Main Bioclastic Limestone of Boston Hill, while laminated dolomite beds in the upper part could correspond to those in the overlying Upper Laminated Limestone.

The Lower Banded Member, a little over 100 ft (30 m) thick, consists of dark fine argillaceous dolomite in the lower half. Alternating finely laminated and massive beds near the bottom grade up into much darker fine dolomite, some of it probably formerly calcareous shale, with a range of lamination types, and some medium-grained crinoidal dolomite. The upper half of the unit consists of variably laminated and streaky dolomite with common and varied burrowing. Correlation with the shaly units above Calcarenite "B" at Boston Hill is likely.

The Laminated Member, c.115 ft (35 m) thick, consists mainly of medium-grained well laminated dolomite, probably former cross-bedded biosparite. The unit is quite unlike the lower ones, though some interbeds are of this type.

The Massive Crinoidal Member, c.100 ft (30 m) thick, consists mainly of fine-grained, slightly streaky dolomite with scattered small crinoid ossicles in diffuse bands. The middle part of the unit is more crinoidal and includes bands of quartz granules in one interval a few feet thick. Correlation of these two units with the Upper Dolomite at Boston Hill is likely.

The Upper Banded Member, c.50 ft (15 m) thick, is a fossiliferous cherty dolomite with shale interbeds, similar to reef-base transition units elsewhere. The overlying reef is about 385 ft (117 m) thick. Part of the supra-reef succession has also been drilled. The Upper Banded Member and higher units are not represented in the Boston Hill cores.

There are general similarities in the overall successions at Wheatfield and Boston Hill. However, most units below the Lower Laminated Limestone of Boston Hill are not recognizable at Wheatfield, where the total thickness is much less. Whether these units are faulted out, condensed or represented by local unconformities, remains to be learnt.

5.4 The Province Boundaries

The limits of the Kildare Province are uncertain at present. The middle part of the succession may extend well south-west of Boston Hill in modified form, as the major wedge of sediments, including laminated silty limestone beds, above the Middle Ballysteen Limestone in the Borris/Templemore area. The Main Bioclastic and Upper Laminated Limestones are certainly present at Monasterevin in Barymin core M-1. North-east of Boston Hill these two units are present, and thicker, at Betaghstown (Noranda cores BT-1 & 2). The eastward continuation and thinning towards Wheatfield was detailed above. The province does not extend as far north as the Trim No.1 well, where the succession is quite different (Sheridan, 1972).

6. Correlation between Stratigraphic Provinces

By definition, lithological successions differ greatly, though not always completely, between provinces. Lithostratigraphic correlation therefore depends on some marker units carrying through at least into marginal areas, to reveal intertonguing relationships. In the absence of such cross-links correlation is a matter of equating unlike units, which is highly speculative without help from biozonation. At present inter-province correlation is very incomplete.

6.1 North Midlands and Dunmore Provinces (Figure 2)

Correlation in the upper part of these successions is relatively straightforward, as thin representatives of the Upper Sandstone and overlying units appear to extend into the Dunmore Province (p.35) Below the Upper Sandstone correlation is more difficult, as the successions differ substantially. At Mount Bellow the shale-dominant sequence with common thin micrite beds below the ?-Upper Sandstone (AG.MB-1, 634 ft) is of Pale Beds type, similar to parts of the Pale Beds at Roscommon and Lough Sheelin. No similar unit is known at Dunmore, where beds immediately below the ?-Upper Sandstone are of sandy and muddy transitional lithologies. Contact with the underlying Basal Sandstone is not represented in core, but the stratigraphic gap is believed from mapping to be small. It is not known to what extent, if any, the Basal Transition Beds and Pale Beds pass laterally into the Basal Sandstone of the Dunmore area.

6.2 Dunmore and Limerick Provinces (Figure 4)

The northward transition from the Limerick Province to the Dunmore Province is illustrated by the four successions from Tynagh to Dunmore. Between Tynagh and Loughrea the succession and thicknesses are similar, except that at Loughrea sandstone and oolite dominate in the lower half of the Middle Ballysteen, and the Upper Ballysteen is disproportionately thin. The reef base may be older here than at Tynagh.

Correlation between Loughrea and Mount Bellew, 17 miles (27.4 km) to the north, is very speculative. The horizon of the reef base shown in the Mount Bellew column is approximate only, but shows that the total thickness of limestone below the reef continues to decrease northwards from Tynagh. Correlation between the top of the ?-Upper Sandstone at Mount Bellew and the isolated 6-in (15-cm) shale at 478 ft in LA-3 follows from the very tentative correlations of the 1045 Marker in figures 3 and 4. The correlation is too uncertain to rule out the possibility that the highest sandstone in the Loughrea succession could be equivalent to the ?-Upper Sandstone at Mount

Bellew. Either way, the sandy and oolitic beds in the Middle Ballysteen at Loughrea could be laterally equivalent to part of the "Pale Beds" at Mount Bellew (i.e. beds below 634 ft). It is possible that the Lower and most of the Middle Ballysteen Limestone pass northwards into Basal Sandstone in the Dunmore Province, as implied by MacDermot and Sevastopulo (1972, fig.5).

6.3 Limerick and North Midlands Provinces (Figure 3)

The most important evidence at present available for correlating the North Midlands and Limerick Provinces is provided by the Cloghan succession. On the basis of good correlation between the Ferbane Mudstone and the Ringmoylan Shales facies at Tynagh (p.43) the Cloghan Sandstone is considered laterally equivalent to the upper part of the Lower Ballysteen Limestone (the top contact of each is not necessarily precisely the same horizon). In the other direction the Cloghan Sandstone extends northwards immediately below the Micrite Unit around the Moate Inlier. The Moate core DM-49 (released for an earlier I.A.E.G. Symposium by Irish Base Metals), though severely faulted, shows that the succession from the Micrite Unit up is generally similar to that at Moyvore. Thus the bottom part of the Pale Beds appears to be laterally equivalent to the lower part of the Middle Ballysteen Limestone.

Interpreted relationship below the Middle Ballysteen/Pale Beds between the Limerick Province and the northern part of the North Midlands Province are illustrated in figure 3. As the Ferbane Mudstone pinches out northwards, the Cloghan Sandstone and Basal Sandstone in the south merge into the Basal Sandstone of the Keel area (possibly north of Moyvore). Relationships with the southern part of the North Midlands Province, exemplified by the Sion Hill succession, are more speculative. However, an anticipated succession between Tynagh and Cloghan would have Ferbane Mudstone overlain by the Cloghan Sandstone overlain by limestone belonging to the top of the Lower Ballysteen. Such a sequence is similar to, if rather simpler than, the Basal Transition Beds succession at Sion Hill. Similar general influences appear to have affected the two areas, even if individual sandstones do not correlate.

Detailed relationships between the higher parts of the North Midlands succession and the Middle and Upper Ballysteen Limestone are obscure. The very tentative correlation between the Upper Shaly Pale Beds and the 1045 Marker at Tynagh (fig. 3) suffers in the first place from uncertainties over the identity of the Upper Shaly Pale Beds in the Moyvore and Windmill Hill successions (p.34). The extended correlation to Cloghan and Tynagh is based partly on the presence of relatively thick shale beds of the same type at about mid-section in each core (the choice of shale bed in the Cloghan succession below 610 ft is almost arbitrary), backed up to some extent by the similar overall successions at Tynagh, Cloghan and Windmill Hill. However, in essence over 1000 ft (300 m) of section below the reef in the Tynagh-Moyvore area cannot be closely correlated from released cores.

The reef base is probably strongly diachronous both within and between these provinces. For example, beds below the reef at Windmill Hill include possible off-reef tongues for 150 ft (45 m) down and cherts for 200 ft (61 m), in contrast to the reef-base transition of not much over 20 ft (6 m) in BR-1. Each of these sequences is underlain by a thick shale unit (BR-1, 156-210 ft; WH-1, 116-139 m), which may well correlate. The reef base at Windmill Hill appears to be appreciably younger than at Cloghan.

6.4 Kildare and Other Provinces (Figure 4)

Relationships between the Kildare Province and the Limerick and North Midlands Provinces are very uncertain, but some general similarities exist. The bottom part of the succession, including the Micrite Unit, is comparable to the Basal Transition Beds and overlying Micrite Unit at Sion Hill. The calcarenites above this, up to the base of the Lower Laminated Limestone, resemble Pale Beds. The main middle part of the succession has some features in common with the Borris Middle Ballysteen and overlying beds, in particular the distinctive laminated silty limestones, but it lacks the thick oolites. The overlying shaly part of the Boston Hill succession slightly resembles the Shaly Pale Beds, Argillaceous Bioclastic Limestone or Upper Ballysteen, but more in its relative position than in lithological detail. The overall succession is thus reminiscent of neighbouring parts of the Limerick and North Midlands Provinces.

7. Stratigraphic Summary

The characteristics of the main units and their inter-relationships are summarized below and in figure 5. It is emphasized that faunal control is sparse, and that conclusions are based on the Symposium holes and published data. A number of important successions, drilled at intermediate locations, remain confidential.

7.1 Old Red Sandstone.---Old Red Sandstone in the Symposium area, where present, overlies the Lower Palaeozoics unconformably. In general it thins northwards, but in the Silvermines area it is anomalously thin (c. 300 ft, 90 m). The thickness is over 800 ft (240 m) near Tynagh, 0-200 ft (60 m) further east, where known. The Old Red Sandstone is divided here into Red Beds and overlying Basal Sandstone; the latter is thick, widespread and usually in sharp contact with the Red Beds.

7.1.a Red Beds.---This term is applied to all Old Red Sandstone units except the Basal Sandstone. Red sandstone and siltstone predominate, but conglomerate is locally important (especially at Navan). Pale grey sandstone similar to the Basal Sandstone can form thick units within the succession. The top contact is sharp in all Symposium cores; in some northern holes it is overlain by Basal Transition Beds rather than Basal Sandstone. Red Beds thicknesses are: Silvermines approximately 230 ft (70 m), Tynagh 620 ft (189 m), Sion Hill 135 ft+ (41 m), Navan 0-50 ft + (15 m), Wheatfield 80 ft + (24 m). Holes between Keel and Crossakeel show localized pockets of Red Beds up to 20 ft (6 m) thick. Holes west of Keel did not reach Red Beds. Lateral relationships with other units are not known. The Lower Palaeozoic surface was probably exposed in the northern part of the area at the end of Red Beds deposition. At Strokestown some red-coloured beds are present, associated with evaporites, in the Pale Beds; i.e. in higher stratigraphic units than elsewhere. However, these are not part of the Old Red Sandstone succession.

7.1.b Basal Sandstone.---This term is applied to the thick pale sandstone at the base of the carbonates across all but the eastern side of the Symposium area. It usually overlies Red Beds, but extends beyond them in the north, to rest directly on the Lower Palaeozoics. Interfingering between Basal Sandstone and Red Beds is not evident from Symposium cores, but probably happens on a broader scale north of the Symposium area, where Red Beds are younger (Clayton & Higgs, 1979; Phillips & Clayton, 1980). The sandstone is generally medium- to coarse-grained and non-calcareous, with subordinate pale green-grey or dark mudstone, mud-flake conglomerate and dark grey siltstone. A very coarse conglomerate forms a basal unit c.40 ft (12 m) thick at Keel and northwards from there. Thickness variation in Symposium holes is less than for the Red Beds: the maximum is c.220 ft (67 m) at Tynagh; Silvermines is again anomalously thin at c.70 ft (21 m); Templemore 120 ft + (36 m). To the north Keel is 180 ft (55 m), Ballinalack 160 ft + (49 m), Newtown Cashel 100 ft + (30 m), thinning further north to 30 ft (10 m) at Granard. Dunmore is 100 ft + (30 m), possibly a lot more.

East of Granard/Ballinalack the Basal Sandstone is absent as a basal unit, but it may possibly tongue into the Basal Transition Beds as one of the thick sandstones at Sion Hill. The upper part of the Basal Sandstone is much younger in the north (e.g. at Keel) than in the Limerick Province, if its interpreted relationship with the Cloghan Sandstone is correct (fig. 5). The Cloghan Sandstone appears to be a southward extension of the upper part of the Basal Sandstone of the Keel area. Sandstones in the Sion Hill Basal Transition Beds may be analogous, though not necessarily contemporaneous. The upper part of the Basal Sandstone at Dunmore may be younger still, possibly laterally equivalent to the lower part of the Pale Beds, unless the latter are highly condensed at Dunmore.

7.2 Basal Transition Beds.---This term is introduced here to cover the very varied successions in the North Midlands Province between the Old Red Sandstone and the Pale Beds. Two broad facies groups are present: 1) the "shaly facies", typified by the Laminated Beds at Navan, consisting of mixed lithologies, usually dominated by heterolithic shale and sandstone, with subordinate thin limestones and isolated thicker sandstone beds; and 2) the "limestone facies", typified by the Muddy Limestone at Navan, mainly argillaceous marine limestone with thin shales. This facies is confined to the upper part of the Basal Transition Beds and to some southern holes.

Basal Transition Beds overlie either Basal Sandstone or, east of Granard/Ballinalack, Red Beds or Lower Palaeozoics. They are thinnest in the central area and thicken east and west: c.400 ft (122 m) at Sion Hill, 180 ft (55 m) at Navan, 30-80 ft (9-24 m) in the Crossakeel-Granard-Ballinalack area. They thin out completely over, and possibly into, the top of the Basal Sandstone in the central area (e.g. at Keel), where Basal Sandstone is overlain directly by Pale Beds. West of Keel modified Basal Transition Beds, including evaporites and reddened sediments, thicken towards Strokestown (250 ft +, 76 m).

Limestone facies occurs at the top of the Sion Hill (100 ft +, 30 m) and Navan successions (c.45 ft, 14 m). It thins out rapidly northwards and is barely recognizable at Crossakeel (c.10 ft, 3 m). It is absent above the ?-Basal Sandstone at Moyvore, where even the shaly facies is only 6 ft (1.8 m) thick.

Relationships to the south are uncertain, but a similar general succession, culminating in marine limestone, is present below the Micrite Unit at Boston Hill and below the Middle Ballysteen Limestone in the north-eastern corner of the Limerick Province. These successions appear to be broadly correlative, and represent a major transgressive sequence, wedging out northwards below the Pale Beds.

7.3 Mellon House Beds.--- This is a transitional unit of fine sandstone, siltstone, and shale, sometimes with limestone, lying between the Basal Sandstone and Ringmoylan Shales in the Limerick Province. The bottom contact is often gradational; the top is sharp.

The unit is c.20 ft (6 m) thick at Silvermines, 30 ft+ (9 m) at Templemore. Northwards it is unrecognizable at Tynagh and Cloghan, and appears to have passed laterally into the top part of the Basal Sandstone. The unit thickens west and south of Silvermines outside the Symposium area (e.g. 125 ft + (38 m) in north Co. Limerick), where there is a distinctive 20-30 ft (6-9 m) sub-unit at the top, the Laminated Shales, characterized by beds of very finely laminated limestone/shale with mudcracks and possible stromatolites. At Silvermines the Mellon House Beds consists almost entirely of Laminated Shales.

7.4 Ringmoylan Shales.--- This unit, consisting mainly of thinly bedded shale and limestone, sharply overlies Mellon House Beds, where present, or Basal Sandstone elsewhere. Its top is defined, for convenience only, by the base of the Ballyvergin Shale. Its thickness, thus defined, varies steadily in the Symposium holes from c.90 ft (27 m) at Templemore to c.45 ft (14 m) at Loughrea. North of Silvermines the Ringmoylan Shales facies extends stratigraphically upwards above the Ballyvergin, accounting for more than half of the Lower Ballysteen Limestone at Tynagh. East of Tynagh the Ballyvergin disappears and the whole shale sequence is then referred to as the "Ferbane Mudstone".

7.5 Ballyvergin Shale.--- This is a unique green non-calcareous silty shale (Clayton et al., 1980) crossing most of the Limerick Province as an important synchronous marker. It demonstrates in particular the diachronous nature of the top of the Ringmoylan Shales facies.

7.6 Lower Ballysteen Limestone.--- This is a thinly bedded limestone and shale unit overlying the Ballyvergin Shale in the Limerick Province. It consists mainly of nodular-bedded argillaceous limestone with thin shales in the Silvermines-Borris area, but northwards the lower part is replaced by Ringmoylan Shales facies; at Tynagh this facies accounts for over half the unit. The top is placed at the sharp upward change to relatively shale-free argillaceous limestones 10-30 ft (3-9 m) below the Fine Calcarenite Marker. The unit is c.120 ft (36.5 m) thick at both Tynagh and Silvermines (earlier thickness differences between these two localities have by this stage been levelled out), c.100 ft (30 m) at Loughrea and Templemore. It passes eastwards from Tynagh into the Cloghan Sandstone and the upper part of the underlying Ferbane Mudstone. The limestones in the upper part of the Lower Ballysteen at Tynagh are analogous to the limestone facies of the Basal Transition Beds at Sion Hill and Navan, in that they overlie sandstones and shales, considered here to belong to the same early transgressive sequence; their age relationships are yet to be established faunally. The limestones in these two areas appear to be separated by Cloghan Sandstone along the Keel-Rosenallis axis.

7.7 Ferbane Mudstone.--- This is a thick shaly unit between Basal Sandstone and the Cloghan Sandstone in the Cloghan-Moate-Rosenallis area. It consists of the generalized upward sequence: siltstone-banded shale, limestone-banded shale, almost pure shale.

The top contact tends to be gradational; the bottom is sharp. The unit thickens from c.160 ft (49 m) at Cloghan to 240 ft+ (73 m) at Rosenallis. Somewhere between the Moate Inlier and Keel it pinches out into the Basal Sandstone (Moyvore data is inconclusive). It correlates with the Ringmoylan Shales facies (partly Lower Ballysteen) at Tynagh. The top of the shale facies gets older and the thickness decreases south-west of Rosenallis towards Borris and Templemore, the Ballyvergin horizon cutting across the facies boundary. North-eastwards the Ferbane Mudstone may extend into the Basal Transition Beds; e.g. as the 70-ft (21-m) shale immediately above Red Beds in the Sion Hill succession. East of Rosenallis the Ferbane Mudstone probably passes into the lower part of the Lower Limestone Shales at Boston Hill.

7.8 Cloghan Sandstone.--- This unit overlies the Ferbane Mudstone in the Cloghan-Rosenallis-Moate area, and consists mainly of varied calcareous sandstone with siltstone and thin biosparites, except in the lower part, which is dominantly banded siltstone and subordinate shale. The bottom contact is gradational over a few feet; the top contact in several holes is absolutely sharp at a stylolitic or brecciated surface, irrespective of which unit overlies it. The unit is c.140 ft (43 m) thick at Rosenallis, 100 ft (30 m) at Cloghan and thinner to the north. The Cloghan Sandstone evidently merges northwards with the Basal Sandstone, to form an extensive central "ridge" separating limestones in the Sion Hill and Tynagh areas. To the west and south it passes laterally into the upper part of the Lower Ballysteen Limestone; the Tynagh Sandy Band may be a thin tongue of it. Towards Boston Hill it presumably passes into the upper, sandier part of the Lower Limestone Shales (fig. 4). The Cloghan Sandstone is overlain by various units: the Micrite Unit (Pale Beds) near the Moate Inlier; a thick oolite at Rosenallis; Middle Ballysteen Limestone at Cloghan.

7.9 Pale Beds.--- This term is applied to the mixed sequences of sandy limestone, micrite, oolite, sandstone and silty shale overlying the Basal Transition Beds in the North Midlands Province. The bottom contact at the base of the Micrite Unit can be interbedded through a few feet. The top contact across most of the province is formed by the sharp base of the Upper Sandstone. Beyond the southern limit of this sandstone (fig. 1) the top is placed at the base of the Shaly Pale Beds, which may be slightly younger. The Pale Beds generally thin northwards from c.700 ft (213 m) at Navan to c.220-250 ft (67-76 m) between Lough Sheelin and Roscommon. They thicken again to c.470 ft (143 m) at Strokestown. There are rapid lateral and vertical facies changes within the Pale Beds; sediments tend to be more open-marine in the south, more marginal- or non-marine in the north, including some evaporites and red beds at Strokestown. Pale Beds pass laterally south-westwards into at least the lower part of the Middle Ballysteen Limestone. They thin out towards the Dunmore Province, but whether by condensing or lateral passage into Basal Sandstone, or both, is not yet known. Detailed relationships with the Boston Hill succession are obscure, but both have a Micrite Unit overlain by oolitic limestone.

7.10 Upper Sandstone.--- This is a relatively thick, pale grey sandstone sharply overlying the Pale Beds across all but the southern part of the North Midlands Province (fig. 1). Very subordinate interbeds of micrite, biosparite and silty shale can be present. The top contact is usually gradational over a few feet into the Shaly Pale Beds. The thickness varies irregularly from c.35 to 150 ft (10-45 m) in the Symposium holes, 60-100 ft (18-30 m) being normal. Similar, but thinner, sandstones are commonly present in the upper part of the underlying Pale Beds. At Moyvore one of these thickens to as much as the Upper Sandstone (c.100 ft, 30 m). From south to north the top of the Upper Sandstone may be getting younger, since the lowest units in the overlying Shaly Pale Beds are progressively lost northwards. Correlation of the Upper Sandstone with the Navan succession is uncertain, but may be with both Shaly Pale Beds and Upper Pale Beds. The Upper Sandstone appears to extend westwards into the Dunmore Province as a thin (13 ft, 4 m) but distinctive sandstone.

7.11 Shaly Pale Beds.--- This mixed unit of sandstone, shale, limestone and intermediate lithologies sharply overlies Upper Sandstone across most of the North Midlands Province, and Pale Beds in the south (e.g. at Navan). Lower, Middle and Upper divisions are clearly distinguishable at Navan, but bottom units are successively lost from south to north, as if passing laterally into the Upper Sandstone. This is accompanied by a reduction in total thickness from south to north from c.360 ft (110 m) at Navan to c.20 ft (6 m) at Granard and Strokestown. Over most of the province the "Shaly Pales" consist typically of a lower sequence of fine calcarenite and burrowed calcareous siltstone, and an upper one including thick black unfossiliferous shale beds with scattered siltstone bands. The top contact can usually be defined at the top of the highest shale over 2 ft (60 cm) thick, but can be gradational into less silty limestone above.

The Moyvore succession presents special correlation problems, because Shaly Pales lithologies, notably the thick silt-banded shale, appear to extend up into the Argillaceous Bioclastic Limestone. At Windmill Hill the distinction between Pale Beds, Shaly Pale Beds and Argillaceous Bioclastic Limestone is even less clear, and appears to reflect general lateral passage from these units into the more homogeneous Ballysteen Limestone. The top of the Shaly Pales is tentatively correlated with the upper part of the Middle Ballysteen Limestone. At Dunmore and Boston Hill the Shaly Pales are unrecognizable.

7.12 Argillacous Bioclastic Limestone.--- This unit (the A.B.L.) is a thick sequence of argillaceous limestone and subordinate shale overlying the Shaly Pale Beds in the North Midlands Province and the probably equivalent transitional beds in the Dunmore Province. The succession is increasingly argillaceous upwards in general, but can include thick shale units well below the top. Local sub-units, based on relatively subtle distinctions, are usually difficult to trace far, but a silty limestone sequence 50-100 ft (15-30 m) thick is normal at the bottom. The top contact is defined by the base of the reef, where present, the highest beds here forming a transitional cherty sequence. Where reef is absent, the A.B.L. extends higher (see "Post-reef A.B.L." below). Thicknesses in the order of 600 ft (180 m) are normal below reef in the North Midlands Province, decreasing irregularly to 150-350 ft (45-106 m) below reef-equivalent beds in northern holes, and c.150 ft (45 m) below the Dunmore reef. South-westwards the A.B.L. is continuous with, and may be indistinguishable from, the Upper Ballysteen Limestone, (and possibly also the upper part of the Middle Ballysteen); the names at present are used according to stratigraphic province. The equivalent at Boston Hill is uncertain.

7.13 Middle and Upper Ballysteen Limestone.--- These units form a thick sequence of argillaceous limestone and subordinate shale sharply overlying the Lower Ballysteen Limestone and Cloghan Sandstone in the Limerick Province. The Middle Ballysteen is mainly more uniform and less argillaceous than the Upper, but the boundary is gradational. The thickness pattern in the Symposium area is irregular. The thinnest successions (550-650 ft, 167-198 m) are at Silvermines and Loughrea; at Tynagh and Cloghan they are 1000-1100 ft (305-335 m); the Templemore-Borris succession reaches 1500-1600 ft (457-488 m). The thickness variation, mainly in the Upper Ballysteen, is partly due to large-scale diachronism at the base of the reef.

At Loughrea the lower part of the Middle Ballysteen includes sandstones and oolites, suggesting lateral passage northwards into a Pale Beds facies. In the Templemore-Borris area the Middle and Upper Ballysteen are separated by a 400-ft (122 m) sequence dominated by thick oolite units and subordinate silty and cherty limestone similar to some Boston Hill units. This suggests large-scale intertonguing between the Limerick and Kildare Provinces. An exceptionally thick (150 ft+, 45 m) shale unit underlies sub-reef cherts at Templemore and probably correlates with a similarly placed shale 50 ft (15 m) thick at Cloghan.

7.14 Waulsortian Reef.--- Distinctive pale grey reef limestone, mainly stromatactis biomicrite, forms a discontinuous unit several hundred feet thick across the Upper Ballysteen and Argillaceous Bioclastic Limestones in the Limerick Province and southern part of the North Midlands Province. Reefs are absent or small and more isolated in northern holes. The base of the reef is visibly diachronous on a local scale; it is inferred to be diachronous on a larger scale from the different thicknesses of sub-reef beds containing probable off-reef tongues (e.g. 200 ft, 61 m of section across 15 miles (24 km) between Cloghan and Windmill Hill; see also Dunmore example, p.36). At present no systematic diachronous pattern has been established within the Symposium area, but there is evidence that the reef base is considerably older around the Shannon Estuary than in the North Midlands (Sevastopulo, 1982). Comtemporaneity between the small Dunmore reefs and the thick (lower) reefs at Keel and Ballinalack is inferred from the correlation of the tuff(s) lying not far above each.

7.15 Post-Reef Argillaceous Bioclastic Limestone.--- Where reefs are absent in the North Midlands and Dunmore Provinces, argillaceous limestones, not substantially different from some of the A.B.L. below, extend upwards above reef-equivalent beds, and are here included within the A.B.L. In order not to obscure lateral relationships (established by the marker tuff), the thick, strongly diachronous chert units are also included within the A.B.L. The post-reef A.B.L. varies considerably in thickness, in lithological succession, and in type of top contact. In western holes 100-300 ft (30-90 m) of post-reef A.B.L. is overlain by clean shelf calcarenites, locally dolomitized (Chadian Oakport Limestone). Similar dolomite sharply overlies approximately 450 ft (137 m) of post-reef A.B.L. at Oldcastle. At Crossakeel post-reef A.B.L. is overlain, probably above an erosion surface, by 30 ft (9 m) of Boulder Conglomerate and then Navan-type Upper Dark Limestones, possibly of Arundian age. At Granard c.160 ft (49 m) of post-reef A.B.L., apparently a very condensed succession, is overlain gradationally by Upper Dark Limestones. No Oakport-type limestones underlie the Upper Dark Limestones at either Granard or Crossakeel. Marked differential subsidence and local erosion have evidently affected the latest A.B.L. units. Further work is required to differentiate units in this part of the succession and properly define the top of the A.B.L. The problem is complicated by the lateral equivalence of these beds with units overlying the thick reefs, as at Ballinalack and Keel, and by a younger, post-tuff reef at both localities.

8. Discussion: The Progress of the Transgression

8.1 The Successions

Tournaisian successions in the Irish Midlands reflect a generally northward transgression across continental deposits in the south and similar sediments surrounding "islands" of bare Lower Palaeozoic rock further north. However, the existence of extensive stratigraphic provinces with substantially differing successions implies that the main facies belts did not migrate steadily northwards, but stabilized for long periods. Furthermore, when there was an advance, environmental conditions changed in the transitional belts, resulting in a distinctly different suite of sediments at the new location (e.g. the Micrite Unit is not represented in the Limerick Province).

At present it is difficult to elaborate the details of the transgression, because lateral equivalence of too many units is uncertain. In particular the amount of diachronism on most unit boundaries is unknown. Some, such as the top of the Ringmoylan Shales facies and the base of the reef, are clearly diachronous. Others, such as the base of the Middle Ballysteen Limestone, appear to be practically synchronous. Time markers as useful as the Ballyvergin Shale and the group of early Visean tuffs have not been identified in the main part of the sub-reef succession. Little biozonation is available from within the Symposium area, and some important cores from transitional areas have not been released. However, some preliminary remarks are possible.

There are several lines of evidence that the progress of the transgression was intermittent. In the south-eastern part of the North Midlands Province and in the Kildare Province there is the "preliminary" transgressive sequence below the Micrite Unit, in which Red Beds are overlain by various marginal marine facies and these in turn by marine limestones, locally including oolite. The overlying Micrite Unit indicates a relatively sudden change to shallow sub-tidal and inter-tidal environments, which were widely distributed. This shallowing is not so obvious in the Limerick Province, where the environment remained fully marine (lower part of the Middle Ballysteen Limestone). However, the Fine Calcarenite Marker, which is interpreted as contemporaneous with part of the Micrite Unit, is an oolite in some places (e.g. Loughrea), indicating shallowing.

Comparable earlier shallowing is represented in the Limerick Province by the Laminated Shales at the top of the Mellon House Beds. This mud-cracked, locally stromatolitic unit overlies marine limestone at Gortdrum ("Transition Limestone"; Thompson, 1967). Silvermines is in a more marginal situation, where the limestone has been replaced laterally by the Basal Sandstone, but the Laminated Shales remain thick. Haematite grains are widespread in calcarenites immediately above the Laminated Shales.

There were, therefore, two episodes of shallowing in the Symposium area before the main phase of the transgression which is represented by the Pale Beds-Argillaceous Bioclastic Limestone (A.B.L.)

Whether the shallowing was due to a general regression or to silting up behind a barrier facies, induced by local uplift, is arguable at present. It is possible, for instance, that the Rosenallis oolites are part of an extensive barrier complex marginal to the North Midlands Province, as tentatively suggested in figure 5. However, their stratigraphic position relative to the North Midlands Micrite Unit is uncertain in view of the oolite below the Boston Hill micrite (fig. 4). On the other hand, the Middle Ballysteen includes subordinate oolite units in marginal successions at various stratigraphic levels (e.g. at Loughrea and Cloghan) and coarse, coated-grain biosparites are locally common at Tynagh and Silvermines. Relatively shallow water seems to be implied, even beyond the limits of the Pale Beds environment at this time. In either case, though, the progress of the transgression was temporarily interrupted.

The main phase of the transgression itself appears to have been irregular. The Pale Beds consist of mainly shallow-marine sediments that accumulated in a wide stable belt (with many sub-environments) during a long period of steady subsidence. The stability of this belt, i.e. the North Midlands Province, is inferred from the thickness of the Pale Beds, combined with the relatively stationary marginal zone, which is expressed in figure 5 as a steep facies contact between the Moate Inlier and Cloghan. Control on the position of the margin is not good from Symposium cores, and the contact in figure 5 could have been drawn with more "northward retreat". However, the significant point is that the width of the rest of the province is much greater. The distinction between "southern" and "northern" facies within the Pale Beds, including the micrites (p.21) is also taken to reflect differentiation within a stable belt.

The Pale Beds contrast strongly with the Argillaceous Bioclastic Limestone/Upper Ballysteen Limestone, representing deeper-water conditions, that later covered the Limerick, Dunmore and North Midlands Provinces and extended well north of the Symposium area. This major marine advance appears to have been a relatively sudden and far-reaching event, if the thick shales near the top of the Shaly Pale Beds are interpreted correctly as extensive, practically synchronous beds.

Evidently then, the Tournaisian transgression across the Irish Midlands proceeded in fits and starts, if not actually interspersed with withdrawals. The reasons for this pattern are probably complex, but some degree of tectonic control is suggested by the unit thickness patterns across the area.

8.2 Thickness Variation

Most of the main stratigraphic units show striking thickness changes across the Symposium area, on both regional and local scales. Figure 5 gives a generalized impression of the regional changes; local variation is apparent in figures 2-4. The best illustrated regional pattern is the thinning of the main units towards the north. Sediments below the Middle Ballysteen/Pale Beds thin from over 1000 ft (300 m) at Tynagh to less than 200 ft (60 m) at Keel (fig. 3) and less than 50 ft (15 m) at Granard and Lough Sheelin (fig. 2). The Red Beds thin out completely within this area from over 600 ft (180 m) at Tynagh. This regional thinning appears to take place partly by overlap (e.g. of the Red Beds) and partly by condensing of successions (as between Sion Hill and Lough Sheelin; discussion on p.15).

Younger sub-reef units within the North Midlands Province also thin from "southern" to "northern" holes (defined p.11), as typified by the adjacent columns for Keel and Granard in figure 2. At this stratigraphic level the thinning is primarily through condensing of the main units, though the lower part of the Shaly Pale Beds appears to be lost northwards also through lateral passage into the Upper Sandstone. If the entire sections below the tuff marker are compared (e.g. Keel v. Granard in fig.2), the thinning is more dramatic, but a large component of this is due to mound-building in the Waulsortian.

The northward thinning of units between Tynagh and Dunmore (fig. 4) also involves condensing, at least of the upper part of the sub-reef succession. Relationships below the A.B.L./Upper Ballysteen are unclear, but a combination of lateral facies change into Basal Sandstone at Dunmore and condensing of units seems likely on present evidence.

Symposium cores are not distributed closely enough to show how rapidly the northward thinning above the Basal Transition Beds takes place, or what is a local rather than regional effect. For instance, although Keel and Granard are 12 miles (19 km) apart, the same amount of thinning may possibly occur across a much shorter distance in the Keel area itself, if the succession north of the Keel Fault is as condensed as at Granard and Newtown Cashel. (N.B. LF-16 and KA-158 were drilled south of the fault complex, which parallels the southern margin of the Keel Inlier.) Even if established here, however, such rapid thinning may not be typical of the transition from "southern" to "northern" holes in the North Midlands Province.

Whatever the regional northward thinning was controlled by, there cannot have been structural continuity between the Longford-Down Massif and the Dunmore area. This is shown by the anomalously thick pre-A.B.L. succession in the intervening Strokestown area (fig. 2), exceeding even that at Keel,. There is insufficient data to outline the shape of the "Strokestown Sag". The thickness of units in the incomplete Roscommon succession below the Shaly Pale Beds is intermediate between Strokestown and Newtown Cashel (fig. 2), but the impression of breadth that this gives may be deceptive. A narrow trough, structurally related to the Strokestown Inlier, may explain the anomalously thick Strokestown sequence.

Not all regional thinning in the Symposium area is "northwards". There is pronounced eastward thinning in the Kildare Province towards the Leinster Massif. Condensing of the main sub-reef units appears to be the principal mechanism, though close to the massif there may also be local erosion surfaces (suggested by the quartz granule horizons at Wheatfield, e.g.). Bruck (1971) noted that earlier "overlap" interpretations were weakly founded. To put the scale of the presently known thinning into perspective, the sub-reef carbonate section at Wheatfield, as pieced together by Strogen and Somerville (in press), even though much thinner than at Boston Hill, is still as thick as at Tynagh (fig. 4).

Superimposed on the regional pattern, and not always easily separable, are local thickness changes at various scales. Few local "upwarps" and basins, formed by differential subsidence, have been identified, but some significant features are illustrated.

The sub-A.B.L. succession is very condensed at Crossakeel relative to Navan and Sion Hill to the south (fig. 3). However, it expands again northwards towards Oldcastle (and becomes sandier) before further condensing towards Lough Sheelin (fig. 2). The distribution of these holes relative to present Lower Palaeozoic outcrop "noses" (fig. 1) suggests the existence of subsiding sub-basins within the North Midlands Province, controlled by Caledonoid-trending structures. Thickness changes in the Keel area may also have been controlled in this way. It seems likely that similar local basins and "upwarps" exist further south in the North Midlands Province, affecting Pale Beds in particular.

In the Limerick Province large-scale thickness changes affect units around the Silvermines area. The Old Red Sandstone thickens from c.350 ft (105 m) at Silvermines to over 800 ft (240 m) at Tynagh (fig. 4). Emo and Grennan (1982, fig. 2) show with isopachs that the main changes occur close to an elongate Caledonoid-trending "upwarp" centered on Silvermines, thicknesses increasing again to the south. However, no significant differential subsidence around this structure is apparent from Symposium cores (or others known to the author) through the Ringmoylan Shales and Lower Ballysteen Limestone; thicknesses appear to vary remarkably little for these units (well controlled by markers) from Templemore to Loughrea (fig. 4). (Bruck (1982) quotes a 50% thickness increase north of Silvermines, but does not state where). Middle Ballysteen thicknesses, though imprecise through poor definition of the top of the unit, do not change greatly between Silvermines and Loughrea, but do towards Borris. The main active element at this time may, therefore, have been a Templemore-Boston Hill trough rather than the Silvermines "upwarp". Comparison of Upper Ballysteen Limestone and reef thicknesses with other areas is complicated by possible large-scale diachronism at the reef base, but Silvermines is somewhat thinner overall than Tynagh. This part of the Borris-Templemore succession is very much thicker than both, which suggests that trough development was again the main activity.

Of particular interest is the strong suggestion that the Silvermines "upwarp" was dormant during deposition of the Ringmoylan Shales and Lower Ballysteen Limestone.

In several parts of the North Midlands Province differential subsidence was not only intermittent, but reversed its sense. The Strokestown succession is the best example (fig. 2), having a sub-A.B.L. succession thicker than Keel, but A.B.L. as thin as in any other Symposium hole. Oldcastle shows a similar reversal, with good control provided by the basal unconformity and the tuff. A reversal in the opposite sense occurs at Crossakeel, where the A.B.L. is exceptionally thick (fig. 3), even allowing for the uncertainty as to the exact level of reef-equivalent beds. These reversals occurred approximately during deposition of the Upper Shaly Pale Beds; i.e. broadly coinciding with the inferred acceleration of the main transgression, which may, therefore, have been tectonically induced.

The limited data from the Symposium cores indicates that differential movements of a more fundamental type occurred in the early part of the Visean, (see also Sevastopulo, 1979). At Navan these led to the major unconformity, above which as much as 2000 ft (600 m) of section appears to have been removed in some places prior to deposition of Arundian sediments. A small unconformity of similar age may be present at Crossakeel below limestone boulder beds (CK-1). The widely differing Visean successions and relative thicknesses in the Symposium cores (p.31) show that a new and quite complicated facies pattern was evolving at this time. Shelf limestones (some now dolomitized) of presumed Chadian age overlie post-tuff Argillaceous Bioclastic Limestone at Oldcastle and much further west at Roscommon. In between at Granard undated thinly bedded limestones and shales (distal turbidites?) similar to the Arundian Upper Dark Limestones of Navan lie a mere 110 ft (34 m) above the tuff.

8.3 Summary

The Symposium cores demonstrate that similar successions can be traced across wide areas of the Irish Midlands, forming four distinct stratigraphic provinces. Successions thin regionally towards three separate "massifs" in the Leinster, Longford-Down and Dunmore areas. Superimposed on the wide facies belts are local, structurally controlled basins and "upwarps", which were active at different times, and which exhibit intermittent and reversed-sense differential subsidence. There is no obvious relationship between thickness patterns and province boundaries. Provinces cover a wider area than local basins, and some "regional" thinning is restricted within a single province. Intermittent tectonic movements may have been partly responsible for the irregular progress of the Tournaisian transgression. There was a significant increase in the scale of movements during the early Visean, leading to fundamental changes in the facies pattern.

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(For a full list of cores quoted and original companies, see Appendix)

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Appendix: List of Boreholes Referred to in Text

Number	Location[1]	Drilled by[2]
AG.MB-1	Mount Bellew	Irish Base Metals (I.B.M.)
B-2	Borris-in-Ossory	Barymin
B-84,-109,-113	Ballinalack	Noranda
B-114		Billiton
BB.82-4	Strokestown	Munster Base Metals
BH-169,-178,-179, -415,-426,-443	Tynagh	I.B.M.
BR-1	Cloghan	Dresser
BT-1,-2	Betaghstown	Noranda
CK-1,-2	Crossakeel	Syngenore
CK-6		Billiton
D-1	Rosenallis	Aquitaine
DM-49	Moate(Moyvoughly)	I.B.M.
GR-1	Roscommon	Aquitaine
GR-5,-20	Granard	Riofinex
KA-158	Keel	Asarco
L.6	Navan	Selection Trust
L-18,-22,-24	Newtown Cashel	Noranda
LA-3	Loughrea	Dresser
LF-16	Keel	Riofinex
LR/EE-1,-3	Roscommon	Aquitaine
LS-14,-52	Lough Sheelin	Riofinex
LS-58,-59,-62	Oldcastle	Billiton
M-1	Monasterevin	Barymin
MGR.82-35	Dunmore	Billiton
MV-8,-11,-12	Moyvore	Amax
N-1	Rosenallis	Aquitaine
SH-4,-16,-35,-42,-43	Sion Hill	Riofinex
Trim No. 1 well		Ambassador
V-25,-40	Silvermines	Mogul
WH-1	Windmill Hill	Aquitaine
74-MG-2,-4,-5	Dunmore	Shallee Exploration
81-3,-4,-5,-8,-9	Templemore	Baroid
82-2	Templemore	Baroid
600-6	Boston Hill	Newmont
600-52		I.B.M.
863/1,-2	Boston Hill	I.B.M.

Footnotes

1. For precise location refer to Company or Geological Survey of Ireland

2. Some cores and data subsequently acquired by other companies; see Acknowledgements.

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