

Chapter 18

Northern Ireland

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During the Carboniferous, Northern Ireland straddled a zone of dextral strike-slip, comparable to the Midland Valley of Scotland (see Chapter 14). The earliest Mississippian marine transgression reached Northern Ireland in the late Tournaisian (CM Miospore Biozone) and from then until the mid-Arnsbergian Substage (E_{2b}1 Subzone) the sediment fill was deposited in close proximity to the northern margin of the basin. Metamorphic rocks of the Central Highlands (Grampian) Terrane to the north were repeatedly exposed during episodes of marine regression. In the southeast of the region it appears that the Southern Uplands-Down-Longford Terrane was finally submerged in the late Asbian or early Brigantian. The cumulative thickness of 7000 m is represented mainly by Tournaisian, Visean and lower Namurian rocks in Co. Fermanagh, the Fintona Block, peripheral sections at Coalisland and isolated basins such as Newtown Stewart, all in Co. Tyrone (Fig. 18.1). The most continuous outcrop and succession extend from Co. Fermanagh and south Co. Tyrone into north Co. Armagh. The Carboniferous outcrop in the eastern part of Northern Ireland is reduced to outliers at Ballycastle in Co. Antrim, and in Co. Down at Cultra, Castle Espie and Carlingford Lough. During the Pennsylvanian, much of Northern Ireland was land, and strata of this age are limited in extent to the Fintona Block and east Co. Tyrone (Fig. 18.1)

Tournaisian

The oldest Carboniferous (Courceyan-CM Biozone) rocks are restricted to the margins of the present outcrop and rest on rocks of the three major terranes that constitute the basement in Northern Ireland, namely the Central Highlands (Grampian), Midland Valley and Southern Uplands-Down-Longford terranes (Anderson *et al.* 2004). They were deposited as the first transgression migrated northwards across Ireland as far north as the Kesh-Omagh area in Co. Fermanagh (Fig. 18.1) and on the north side of the Southern Uplands-Down-Longford Terrane in Counties Armagh and Down. However, in many areas originally covered by those deposits, particularly along the north side of the depositional basin, uplift, folding and erosion removed the oldest Carboniferous rocks. After that localised tectonic episode, the outcrop of Courceyan rocks was limited to the Omagh Sandstone Group in the Kesh-Omagh area, the Roe Valley Group, which was deposited in a separate intra-cratonic non-marine basin on the Central Highlands (Grampian) Terrane in Co. Londonderry and the Holywood Group in Co. Down (Mitchell 2004; Fig. 18.2, Cols. 4, 7 & 8). Continuous Courceyan-Chadian sedimentation in the Tyrone Group is restricted to the areas of south Co. Fermanagh and Co. Armagh (Fig. 18.2, Cols. 2 & 5). After the transitory episode of marine regression in the late Courceyan, the sea once again returned in the late Tournaisian and drowned large areas of the Central Highlands (Grampian) Terrane and the Southern Uplands-Down-Longford Terrane. The Tyrone Group mostly comprises a regular succession of formations consisting of

marine sedimentary rocks that were deposited between the late Courcayan and early Brigantian (Mitchell 2004; Cózar *et al.* 2006).

At the northern margin of the Carboniferous outcrop in Co. Fermanagh the Omagh Sandstone Group rests on Neoproterozoic metamorphic rocks of the Dalradian Supergroup and is overlain unconformably by the Chadian Claragh Sandstone Formation (GSNI 1995; Mitchell 2004). Miospore assemblages from the Omagh Sandstone Group contain *Auroraspora macra* and *Schopfites claviger* and indicate the CM Biozone (Fig. 18.2, Col. 4¹). The lacustrine, fluvial and shallow marine rocks in the Newtown Stewart Outlier, Co. Tyrone (GSNI 1997) rest unconformably on Dalradian metamorphic rocks. Late Tournaisian miospore assemblages include rare *Lycospora* indicating the basal Pu Biozone².

The outcrop of the Roe Valley Group is located on the eastern margin of the outcrop of Dalradian rocks in the Sperrin Mountains in east Co. Londonderry (Fig. 18.2, Col. 7). The basal, unfossiliferous, Spincha Burn Conglomerate Formation is succeeded by the non-marine Barony Glen Formation, which contains miospore assemblages indicative of the CM Biozone¹ (Mitchell, 2004).

The isolated outcrop of the Tournaisian Holywood Group at Cultra in north Co. Down (Fig. 18.2, Col. 8) consists of unfossiliferous basal red alluvial deposits, the Craigavad Sandstone Formation, resting unconformably on deformed Ordovician rocks of the Southern Uplands-Down-Longford Terrane (Griffith & Wilson 1982). The succeeding Ballycultra Formation contains miospores (Clayton 1986) including *Auroraspora macra* and *Schopfites claviger*, of the CM Biozone¹.

The Tyrone Group rests unconformably either on earlier Tournaisian strata or on a variety of 'basement' rocks ranging in age from Moinian to Devonian (Fig. 18.2). The oldest rocks of the Tyrone Group were deposited in terrestrial, fluvial and peritidal environments and are late Tournaisian, based on the presence of rare *Lycospora pusilla* indicating the basal Pu Biozone. In much of Counties Fermanagh and Tyrone (Fig. 18.2, Col. 3) the basal, unfossiliferous, Ballyness Formation consists of red alluvial deposits and is succeeded by the Clogher Valley Formation which contains miospores and, in the upper part, a late Tournaisian marine fauna with the solitary coral *Siphonophyllia cylindrica* and low diversity assemblages of foraminifers lacking *Eoparastaffella*^{*O1}. In west Co. Fermanagh, west of the Pettigoe Fault, the shallow marine and peritidal Keenaghan Shale Formation (GSNI 1994) rests unconformably on the Moinian Lough Derg Group and contains miospores including rare *Lycospora pusilla* and abundant *Prolycospora rugulosa*, which is characteristic of the Pu Biozone and an early Chadian age (Fig. 18.2, Col. 1¹). The lowest strata of the succeeding Ballyshannon Limestone Formation are Waulsortian limestones of the Magherameena Limestone Member (GSNI 1994). Sub-Waulsortian limestones contain rare foraminifers including *Eotextularia diversa* and *Tetrataxis* and the microproblematicum *Sphaerinvia piai*, indicating a late Tournaisian age^{OT2}. Waulsortian limestones also occur in Co. Fermanagh at Bellanaleck, south of Enniskillen and include the late Tournaisian trilobite taxa *Bollandia cf. rugiceps* and *Cummingella* sp. nov.^{OT2} (Riley 1993). The basal, unfossiliferous red-beds of the Tyrone Group in south Co. Londonderry are referred to the Iniscarn Formation and rest unconformably on rocks of both the Central Highlands (Grampian) and Midland Valley terranes (Cameron & Old 1997; Fig. 18.2, Col. 7). They are succeeded by the

shallow water, peritidal and evaporitic Altagoan Formation with a basal Pu Biozone miospore assemblage including rare specimens of *Lycospora pusilla* of late Tournaisian age ^{^2}.

Tournaisian strata in the subsurface in Co. Fermanagh are proved in deep boreholes (Philcox *et al.* 1992). In south Co. Fermanagh, south of Lisnaskea (Fig. 18.2, Col. 2), and in the adjacent part of north Co. Monaghan, the poorly exposed Tournaisian succession comprises four formations, the lowermost of which rests unconformably on deformed Ordovician rocks of the Southern Uplands-Down-Longford Terrane (Geraghty 1997). Unfossiliferous red-beds of the basal Fearnaght Formation are succeeded by the evaporitic to marginal marine Cooldarragh Formation, marine sandstone of the Ulster Canal Formation with marine limestone and mudstone of the Ballysteen Formation at the top (Fig. 18.2, Col. 2). Beneath the oldest exposed unit, the Ballyshannon Limestone Formation, the Kilbryan Limestone Formation consists of argillaceous bioturbated limestone and subordinate mudstone and attains a maximum thickness in the Big Dog and Slisgarrow boreholes, located between Derrygonnelly and Garrison. The CM-Pu biozonal boundary ^{^1} is located near the base of this formation.

In Co. Armagh, the Tyrone Group succession is determined in the Wilson's Bridge Borehole (Somerville *et al.* 2001) and in river sections (GSNI 1984) (Fig. 18.2, Col. 5). The Killuney Conglomerate Formation, the unfossiliferous basal unit of red-beds, rests unconformably on deformed Ordovician rocks of the Southern Uplands-Down-Longford Terrane. Miospores in the succeeding Retreat Siltstone Formation include *Auroraspora macra* and *Schopfites claviger*, the index taxa of the CM Biozone ^{^1}. In the Ballynahone Micrite Formation miospore assemblages from 4 m above the base contain the same taxa of the CM Biozone and the lowest, rare, specimens of *Lycospora pusilla* thus indicating the basal Pu Biozone and a late Tournaisian age ^{^2}. Conodonts recorded 28 m below the top of the Ballynahone Micrite Formation include *Mestognathus praebeckmanni*, *M. beckmanni* and *Polygnathus bischoffi* of Tournaisian age ⁰³.

Visean

In many parts of Northern Ireland marine conditions persisted from Chadian to Asbian times with only minor interruptions. During that period it is likely that the Dalradian rocks in the Sperrin Mountains were submerged at times of maximum transgression, principally during deposition of the Bundoran Shale and Benbulbin Shale formations. Conversely, it is also likely that at least some parts of the Southern Uplands-Down-Longford Terrane were emergent at all times until the Brigantian.

The distinctive sequence of sedimentary rocks that constitute the Tyrone Group were deposited in Northern Ireland by a marine transgression that commenced in the late Tournaisian, prior to the first appearance of *Eoparastaffella*, and continued into the late Asbian. The standard succession, which was first described in Co. Sligo in northwest Ireland (Oswald 1955), is also recognised throughout Co. Fermanagh and the Clogher Valley area of Co. Tyrone (Fig. 18.1) and comprises the Ballyshannon Limestone, Bundoran Shale, Mullaghmore Sandstone, Benbulbin Shale, Glencar Limestone and Dartry Limestone formations (GSNI 1997; Fig. 18.2, Cols. 1 & 2). In those formations there is evidence of marine transgression and increasing water depths, but the top of most formations corresponds to a transitory episode of regression.

In the Kesh-Omagh area (Fig. 18.2, Col. 4), the lower part of the Tyrone Group is augmented by formations of predominantly clastic composition that formed in response to episodes of regression and transgression, and the periodic proximity of the northern landmass (GSNI 1995). The lowest unit, the Claragh Sandstone Formation oversteps the Omagh Sandstone Group to the west and rests unconformably on Dalradian metamorphic rocks. Its Chadian age is based on the occurrence of miospore assemblages with *Lycospora pusilla*^{^3} and of the occurrence of mono- and bilaminar *Koninckopora*. The succeeding peritidal Termon River Limestone Formation contains a sparse coral fauna with *Dorlodotia pseudovermiculare*, monolaminar *Koninckopora* and foraminifers including *Eoparastaffella* but no archaedicids^{*04}. At the northern edge of the Carboniferous outcrop the Termon River Limestone Formation is replaced by the partly contemporaneous, shallow marine, Bin Mountain Sandstone Formation which succeeds the Claragh Sandstone Formation and contains, in the lower part, a microfauna including monolaminar *Koninckopora* and the foraminifers *Biorbis duplex*, *Endothyra laxa*, *Eoparastaffella* and *Florenella stricta*. Higher strata in the Bin Mountain Sandstone Formation contain an assemblage of foraminifers including *Glomodiscus*, *Uralodiscus* and *Viseidiscus umbogmaensis* indicating an early Arundian age⁰⁵.

The Ballyshannon Limestone Formation is divided into three informal 'members'. The lower and middle 'members' contain a Chadian microfauna including *Eoparastaffella simplex* and monolaminar *Koninckopora* while the upper 'member' has a mid-Arundian microfauna dominated by the archaedicids *Glomodiscus*, *Uralodiscus*, and *Paraarchaediscus @ involutus* stage (Legg *et al.* 1998). In the Kesh-Omagh area (Fig. 18.2, Col. 4) the basal 5 m of the formation contain the corals *Dorlodotia pseudovermiculare*, *D. cf. briarti* and *Siphonodendron martini* associated with microfaunas of Chadian (Cf4 α 2)^{*6}, early Arundian (Cf4 β - γ)^{*7} and mid-Arundian (Cf4 δ)^{*8} age, respectively. In this area (GSNI 1995) a widespread episode of shallowing is indicated in the upper part of the formation. At Lisnaskea, Co. Fermanagh a grainstone, the Newtownbutler Limestone Member (20 m), represents the top of the formation (Mitchell 1995).

The middle to upper Arundian Bundoran Shale Formation contains abundant brachiopods including *Delepinea carinata* and *D. destinezi*, the corals *Koninckophyllum carlyanense*, *K. fragile*, *Siphonophyllia caninoides*, *S. garwoodi*, *Siphonodendron martini* and *S. sociale* and the mid-Arundian foraminifers *Glomodiscus*, *Lysella* and *Paraarchaediscus @ involutus* stage (Fig. 18.2, Cols. 1^{*03}, 2^{*02}, 3^{*02} & 4^{*09}). Its most easterly exposure is within the Clogher Valley Fault zone, east of Aughnacloy (GSNI 1982), but the formation is not represented in the Tyrone Group succession in Co. Armagh. Sandstone occurs commonly at or just above the base of the formation, with the Dowra Sandstone Member (53 m) present in Co. Fermanagh (Sheridan 1972; Philcox *et al.* 1992), the Skea Sandstone Member (1.4-20 m) in the Kesh-Omagh area (GSNI, 1995), which infills a palaeovalley in the top of the Ballyshannon Limestone Formation (Mitchell 2004) and the Mullynagowan Sandstone Member (2 m) in south Co. Fermanagh (Mitchell, 1995).

The deltaic Mullaghmore Sandstone Formation occurs throughout Co. Fermanagh with the exception of part of the Lisnaskea area. Near Derrygonnelly in Co. Fermanagh (Fig. 18.2, Col. 1⁰⁴), in the Kesh-Omagh area (Fig. 18.2, Col. 4⁰¹⁰) and at Fardross in south Co. Tyrone the top bed contains the mid- to late Arundian foraminifers *Glomodiscus*, *Paraarchaediscus @ involutus* stage and *Uralodiscus*. The Drumchorick Siltstone Formation (GSNI 1995) only occurs in the Kesh-Omagh

area and is transitional between the Mullaghmore Sandstone and Benbulbin Shale formations (Fig. 18.2, Col. 4). There is a vertical passage from mid-shelf coralliferous facies to outer shelf with turbiditic limestone. Colonial corals display a 'cerioid tendency' and possess features of both *Siphonodendron* and *Lithostrotion* and are associated with the foraminifers *Eotextularia*, *Paraarchaediscus* @ *involutus* stage and possibly @ *concausus* stage indicating a position just below the Arundian-Holkerian boundary⁰¹¹ (Riley 1993). Thin limestone near the base of the Benbulbin Shale Formation contain *Lithostrotion portlocki* and the late Arundian to early Holkerian foraminifers cf. *Uralodiscus* and *Paraarchaediscus* @ *involutus* stage (Fig. 18.2, Col. 3 *⁰³) while younger limestones contain Holkerian foraminifers such as *Paraarchaediscus* cf. *concausus* stage⁰⁴. At Fardross, a limestone located 8.5 m above the base of the formation contains the late Arundian foraminiferan *Kasachstanodiscus settlensis* and at 25-30 m above the base the brachiopod *Gigantoproductus* sp. cf. *semiglobosus* and *Lithostrotion decipiens* is indicative of the Asbian (Mitchell 2004). Higher turbiditic limestone beds contain the early Asbian foraminiferan *Endothyra archerbecki*, brachiopod *Gigantoproductus*, solitary coral *Siphonophyllia benburbensis* and species of *Siphonodendron*. The Tubbrid Sandstone Formation only occurs in the Kesh-Omagh area and is probably Holkerian in age (GSNI 1995; Fig. 18.2, Col. 4).

In Co. Fermanagh (Fig. 18.2, Col. 1), the base of the Glencar Limestone Formation is transitional from the Benbulbin Shale Formation, while the top is succeeded abruptly by the Dartry Limestone Formation (Legg *et al.* 1998). The Glencar Limestone Formation is absent in the Lisnaskea area, but at Fardross contains an Asbian fauna including *Gigantoproductus*, *Siphonodendron pauciradiale* and *Siphonophyllia benburbensis* (= *S. samsonensis* auctt.) and a microbiota with *angulatus* stage *Archaediscus*. The Dartry Limestone Formation, the highest unit of the Tyrone Group, comprises faunally impoverished deep-water carbonate rocks. Syn-sedimentary faulting led to the creation within the basin of shallower water ramps on which developed micrite mounds of the basal Knockmore Limestone Member (130 m thick) (Kelly 1996; Legg *et al.* 1998; Mitchell 2004). In the Marble Arch-Cuilcagh Mountain area (Fig. 18.2, Col. 1⁰⁵) the 1.3 m-thick Cloghany Limestone Member contains the foraminifers *Paraarchaediscids* @ *angulatus* stage and *Vissariotaxis* cf. *compressa* and is Asbian (Legg *et al.* 1998).

The upper part of the Tyrone Group at Benburb comprises four formations (Mitchell & Mitchell 1983; Fig. 18.2, Col. 3). The Aughnacloy Sandstone Formation contains TC Biozone miospore assemblages including *Schulzospora campyloptera*, *Waltzispore planiangulata* and *Cribrosporites cribellatus* and a macrofauna with *Gigantoproductus* and *Siphonophyllia benburbensis* and is Holkerian to early Asbian^{^5} (Mitchell 2004). The equivalent clastic unit in east Co. Tyrone, near Dungannon, the Carland Sandstone Formation (Fowler & Robbie 1961) also contains miospore assemblages with *Perotrilites tessellatus* of the TC Biozone (Fig. 18.2, Col. 6^{^1}). The top of the succession in the Aughnacloy area (Fig. 18.2, Col. 3) is the Maydown Limestone Formation, the basal part of which includes lithologies reminiscent of the sequence in Co. Fermanagh consisting of the Benbulbin Shale, Glencar Limestone and Dartry Limestone formations. The Maydown Limestone Formation contains an early Asbian macrofauna^{*6} including the brachiopod *Gigantoproductus* sp. *maximus* group, and corals *Lithostrotion araneum*, *Siphonodendron pauciradiale* and *Siphonophyllia benburbensis*, which persists into the succeeding Blackstones Limestone Formation. The deltaic Carrickaness Sandstone Formation contains

miospore assemblages with *Raistrickia nigra*, *Tripartites* cf. *distinctus*, and *Triquitrites marginatus* of the late Asbian NM Biozone ^{^7} (DP Subzone; Clayton 1978, 1985; Clayton *et al.* 2003; Mitchell 2004). At the top of the succession the Blackwater Limestone Formation is divided into six members with the Asbian-Brigantian boundary located at the top of the Glenview Limestone Member (3 m), based primarily on the presence of the bivalve *Posidonia becheri* and the absence of the alga *Koninckopora* in higher members ^{~8}.

The Tyrone Group succession in Co. Armagh and east Co. Tyrone is attenuated, clastic dominated and bears no resemblance to the succession elsewhere in Northern Ireland (Somerville *et al.* 2001). In Co. Armagh (Fig. 18.2, Col. 5) the Tournaisian-Visean boundary is located 6 m below the top of the Ballynahone Micrite Formation at the first record of the foraminiferan *Eoparastaffella simplex* ⁰⁴ (Somerville *et al.* 2001). The succeeding, non-marine, Milford Mills Formation contains miospores of the Pu Biozone ^{^5} in the lower part and is Chadian to possibly early Arundian in age (Somerville *et al.* 2001). The fossiliferous marine limestone of the Oulart Villa Limestone Formation contain the corals *Dorlodotia pseudovermiculare* and *Siphonodendron martini* in the lower part associated with the foraminifers *Eoparastaffella simplex* and *Glomodiscus oblongus* of early to mid-Arundian age ^{*06}. The highest limestones contain a mid- to late Arundian microfauna including *Paraarchaediscus @ involutus* stage ⁰⁷. A thin limestone bed near the base of the Drumman More Sandstone Formation with *Lithostrotion* corals and paraarchaediscid foraminifers @ *concaus* stage is probably Holkerian ^{*08}, but miospore assemblages of the TC Biozone with *Perotrilites tessellatus* in the upper part may be early Asbian ^{^9}.

An extended period of tectonic uplift and non-deposition in the Draperstown area on the southern edge of the Central Highlands (Grampian) Terrane produced an unconformity that extends from the latest Tournaisian to the late Visean (Asbian). In the eastern part of Northern Ireland isolated outliers of Visean rocks occur at Ballycastle in north Co. Antrim and in Co. Down at Castle Espie and Carlingford. In south Co. Down limestones of the Carlingford Limestone Group crop out on the north shore of Carlingford Lough and rest unconformably on deformed Silurian rocks of the Southern Uplands-Down-Longford Terrane (Fig. 18.2, Col. 8). The mid- to late Arundian age is based on the presence of foraminifers including *Glomodiscus* and *Paraarchaediscus @ involutus* stage and a macrofauna with the brachiopod *Delepinea carinata*, and corals *Siphonodendron martini* and *Siphonophyllia garwoodi* ^{*02} (Mitchell 2004).

With the exception of the widespread Meenymore Formation and an isolated outcrop in east Co. Tyrone, the most complete section of the Leitrim Group is on Cuilcagh Mountain in Co. Fermanagh (Fig. 18.2, Col. 1). In the lower part of the Leitrim Group the Meenymore, Glenade Sandstone and Bellavally formations were deposited in very shallow marine, sabkha, evaporitic and deltaic environments (Brunton & Mason 1979; Legg *et al.* 1998; Mitchell 2004). The succeeding Carraun Shale Formation represents the top of the Visean succession and is the start of hemipelagic shale basin conditions which may eventually have spread across much of Northern Ireland. The base of the Meenymore Formation is disconformable on the Dartry Limestone Formation. Biostratigraphically important foraminiferan and algal taxa of Brigantian (Cf6δ Subzone) age such as *Archaediscus karreri* group, *Asteroarchaediscus baschkiricus*, *Fasciella crustosa* and *Clara crusta catenoides* occur in the lower part of the

Meenymore Formation ⁰⁶ (Cózar *et al.* 2006). The succeeding deltaic Glenade Sandstone Formation contains miospore assemblages of the NM Biozone, which may, however, be reworked. Brigantian ammonoid faunas occur in marine bands in the Bellavally Formation. They range from the early Brigantian P_{1a/b} Zones in the basal Larkfield Shale Member (4.4 m) and higher Lugasnaghta Shale Member (5 m), with *Beyrichoceratoides* (= *Eoglyphioceras*) *truncatum* and *Goniatites* cf. *globostriatus*, to the P_{1b} Zone ammonoids *Arnsbergites falcatus* and *Goniatites concentricus* in the higher Glenkeel Member (c. 4 m) and Sheena Shale Member (c. 5 m) ⁺⁷ (Brandon & Hodson 1984; Legg *et al.* 1998). Miospore assemblages of the VF Biozone (Brigantian) are recorded from the Bellavally Formation (Higgs 1988). The Carraun Shale Formation is fossiliferous throughout the mudstone sequence, but the diagnostic ammonoid taxa are present only in four thin, but regionally persistent, limestone beds. The basal Derreens Limestone Member (0.8-1.5 m) contains *Arnsbergites sphaericostriatus*, *Goniatites lepidus* and *Hibernioceras carraunense* of the P_{1c} Zone ⁺⁸. In the upper part of the formation the Ardvarney Limestone Member (0.3 m) contains *Lusitanoceras granosus* (= *L. poststriatum*) and *Sudeticeras crenistriatus* of the P_{2a} Zone ⁺⁹, the Sranagross Member (0.2 m) contains *Lusitanites subcircularis* and *Sudeticeras ordinatum* of the P_{2b} Zone ⁺¹⁰ and the Camderry Member (0.27 m), located a few metres below the conformable Viséan–Namurian boundary, includes the late Brigantian ammonoids *Lyrogoniatites georgiensis* and *Girtyoceras waitei* of the P_{2c} Zone ⁺¹¹.

The outcrop of the Alderwood Mudstone Formation (c. 200 m) in the footwall of the Clogher Valley Fault, south of Fivemiletown is isolated from the main outcrop of the Leitrim Group and includes the P_{2a} Zone (early Brigantian) trilobite *Paladin bakewellensis* (Mitchell 2004). The hemipelagic Rossmore Mudstone Formation (Robbie 1955) is only exposed in the Dungannon area of east Co. Tyrone (Fig. 18.2, Col. 6 ⁺⁵) and contains the ammonoid *Sudeticeras crenistriatus*, an index taxon for the P_{2a} Biozone. The upper part contains no diagnostic fauna and may range into the Pendleian substage (early Namurian).

In Co. Armagh the Tyrone Group is succeeded by the wholly marine Armagh Group, which consists of three formations of late Asbian to late Brigantian age (Somerville *et al.* 2001; Mitchell 2004; Fig. 18.2, Col. 5). The basal limestone of the Wilson's Bridge Limestone Formation includes the alga *Koninckopora inflata* and foraminiferan *Koskinobigenerina* suggesting a late Asbian or early Brigantian age ⁰¹⁰. The age of grainstone units of the Loughgall Limestone Formation is equivocal and contains *angulatus* stage archaedicids and *Koninckopora*. At outcrop it also includes purplish red palaeokarstic limestone, red mudstone and siltstone, lenticular coarse-grained sandstone, and coral and limestone cobble conglomerate. The macrofauna of the Carganamuck Limestone Formation includes a rich Brigantian coral assemblage (Somerville *et al.* 2001; Cózar *et al.* 2005; Rodríguez & Somerville 2007). The presence of the foraminiferan *Howchinia bradyana* and the absence of *Koninckopora* are also characteristic of the early Brigantian ⁰¹¹. However, in the upper part of the Carganamuck Limestone Formation a mid- to late Brigantian age is established from the presence of the conodont *Lochriea nodosa* and foraminifers *Endothyranopsis sphaerica*, *Climacammina* sp., *Janischewskina typica*, *Biseriella parva* and the calcareous alga *Calcifolium okense* ⁰¹² (Cózar *et al.* 2005).

Between Dungannon and Coalisland in east Co. Tyrone the Armagh Group comprises the partly contemporaneous Derryloran Grit Formation (Fowler & Robbie 1961) and the Rockdale Limestone Formation (Cameron & Old 1997; Fig. 18.2, Col. 6).

Together with an abundant macrofauna in the Rockdale Limestone Formation which includes the corals *Lonsdaleia duplicata*, *Diphyphyllum lateseptatum*, *Koninckophyllum magnificum* and *K. interruptum* (Somerville 1999), algae and foraminifers help to establish the precise position of the early Asbian-late Asbian *⁰², late Asbian-early Brigantian *⁰³ and early Brigantian-late Brigantian *⁰⁴ boundaries (Mitchell 2004, fig. 7.7; Cózar *et al.* 2005). Conodont faunas of the mid- to late Brigantian *Lochriea nodosa* Biozone occur near the top (Somerville 1999; Cózar *et al.* 2005). The late Brigantian age of the upper part of the Rockdale Limestone Formation is defined by the presence of the foraminifers *Endothyranopsis sphaerica*, *Climacammina* sp., *Janischewskina typica* and *Biseriella parva* and the calcareous alga *Calcifolium okense* (Cózar *et al.* 2005).

In the Draperstown area of south Co. Londonderry and on the slopes of Slieve Gallion (Fig. 18.2, Col. 7) the Armagh Group comprises the late Asbian Desertmartin Limestone Formation with a macrofauna *³ including the coral *Lithostrotion portlocki* and brachiopod *Gigantoproductus* sp. cf. *semiglobosus*. An isolated outcrop of the Leitrim Group Meenymore Formation (early Brigantian) represents the youngest Carboniferous unit in this area (Cameron & Old 1997).

In the central part of Northern Ireland, rapid uplift of basement rocks of both the Central Highlands (Grampian) and Midland Valley terranes during the late Holkerian and early Asbian led to the erosion of at least 2000 m of strata of the Tyrone Group from the area of the Fintona Block. Deposition of continental alluvium of the Kilskeery Group (Fig. 18.2, Col. 4) commenced in the area of the Fintona Block in the late Asbian and was followed, to the north, by deposition of Brigantian red-beds of the Greenan Sandstone Formation (Fig. 18.2, Col. 4) in a separate basin in Co. Tyrone (Mitchell & Owens 1990). Miospore assemblages in the basal Topped Mountain Sandstone Formation include *Knoxisporites stephanephorus*, *Vallatisporites ciliaris*, *Schulzospora* sp. cf. *elongata* and *Tripartites vetustus* of the NM and VF biozones ¹² (late Asbian and early Brigantian). Succeeding the unfossiliferous Ballyreagh Conglomerate Formation, the Ballinamallard Mudstone Formation contains miospore assemblages with *Reticulatisporites carnosus*, indicating the NC Biozone ¹⁴ and a late Brigantian-Pendleian age. The partly equivalent Greenan Sandstone Formation was deposited in a separate non-marine basin from the Kilskeery Group and contains miospore assemblages with *Schulzospora campyloptera*, *Tripartites vetustus* and *Verrucosisporites morulatus* and, in particular, *Rotaspora knoxi* that appears in the VF Biozone ¹³ (early Brigantian). Contemporaneous rhyolitic lavas occur near the top of the formation in the outcrop east of Omagh (Mitchell 2004).

In north Co. Antrim, the clastic-dominated, coal-bearing Ballycastle Group rests unconformably on Dalradian metamorphic rocks (Fig. 18.2, Col. 8). Miospores in the basal beds include *Grandispora spinosa*, which first appears in the Brigantian VF Biozone ³ (Mitchell, 2004). An ammonoid fauna with *Sudeticeras adeps*, indicating the late Brigantian P_{2b} Zone ⁺⁴, occurs just below the Visean-Serpukhovian (Namurian) boundary, which corresponds to the base of the Main Coal (Wilson & Robbie 1966). The lowest preserved strata of the Carboniferous section in the Magilligan Borehole, located west of Ballycastle, form part of a coal-bearing deltaic sequence (Bazley *et al.* 1997) and contain early Brigantian (VF Biozone) miospores including *Crassispora maculosa* and *Rotaspora knoxi*.

Marine limestone of the Castle Espie Group crop out at the north end of Strangford Lough in Co. Down (Fig. 18.2, Col. 8). They are unconformable on Silurian rocks of the Southern Uplands-Down-Longford Terrane and contain Brigantian foraminifers⁰⁵ including *Loeblichia paraammonoides* and *Saccamminopsis fusulinaeformis* (Smith *et al.* 1991).

Namurian

In Northern Ireland early Namurian successions were deposited in a paralic environment. This change from the underlying mainly marine Viséan strata is related to an increase in tectonic activity and localised uplift in Northern Ireland, and in Co. Fermanagh to the deposition of the Kilskeery Group and Greenan Sandstone Formation (Fig. 18.2, Col. 4) in two, new, non-marine sedimentary basins. During the early Namurian the hemipelagic mudstone and sandstone of the upper part of the Leitrim Group extended across Counties Armagh, Londonderry and Tyrone.

The upper part of the Leitrim Group is only exposed in Northern Ireland on Cuilcagh Mountain in Co. Fermanagh (Legg *et al.* 1998; Fig. 18.2, Col. 1). Four marine bands in the Dergvone Shale Formation contain the ammonoids *Cravenoceras* (= *Emstites*) *leion*⁺¹², *C. brandoni*, *Tumulites pseudobilinguis*, and *C. malhamense* of Pendleian age. The higher Gowlaun Shale Formation includes the ammonoid *Eumorphoceras bisulcatum* of Arnsbergian (E_{2a-b}) age⁺¹³. The Briscloonagh Sandstone and Lackagh Sandstone formations were deposited on deltas of northern provenance with the development of coal swamps on the younger delta.

In the Ballycastle area of north Co. Antrim sedimentation was continuous across the Viséan-Namurian boundary (Wilson & Robbie 1966). The base of the Namurian is placed at the base of the Main Coal and evidence for the presence of Namurian strata is based on the occurrence of miospores including *Pustulatisporites papillosus*, which first appears in the Pendleian NC Biozone (Whittaker & Butterworth 1978).

The Millstone Grit Group is only exposed in the Dungannon-Coalisland area of Co. Tyrone (GSNI 1960) comprising pebbly sandstone, sandstone, mudstone with marine fossils, thin beds of crinoidal limestone, seatearths and coal seams. Microflora confirm that the Millstone Grit is divided into two parts (Fowler & Robbie 1961; Ramsbottom *et al.* 1978). In the lower part, strata contain miospores of the NC and TK biozones (Pendleian and Arnsbergian substages) which are not younger than the E_{2b} ammonoid zone (Fig. 18.2, Col. 6^{^6}). Millstone Grit strata above the mid-Namurian hiatus contain the taxa *Ibrahimisporites* cf. *magnificus*, *Raistrickia fulva* and *Reinschospora speciosa* which are characteristic of the FR Biozone^{^7} (upper Marsdenian-Yeadonian substages).

Westphalian

The Slievebane Group (Fig. 18.2, Col. 4) is confined to fault bounded slivers along the Omagh Thrust Fault in Counties Fermanagh and Tyrone and the Coal Measures Group (Fig. 18.2, Col. 6; Fig. 18.3) to the Coalisland Coalfield in Co. Tyrone. Sedimentary rocks of the alluvial plain and coal swamp facies associations were deposited throughout Langsettian times and into the early Duckmantian but were disrupted by uplift of Dalradian basement to the north, subsidence of a continental basin along the trace of the Omagh Thrust Fault and deposition of volcanoclastic conglomerate and sandstone.

At the base of the Slievebane Group, the Tullanaglare Mudstone Formation contains a Westphalian microflora of late Langsettian (RA Biozone) and early Duckmantian (NJ Biozone) age (Mitchell & Owens 1990; Fig. 18.2, Col. 4 ¹⁵). At the top of the formation the Drumgivery Limestone Member (0.5 m), a bed of calcrete, is succeeded by the volcanoclastic Drumlish Conglomerate Formation with large clasts of fresh trachybasalt and trachyandesite. Late Variscan strike-slip movement and thrusting on the Omagh Thrust Fault has severely disrupted and curtailed the outcrop of the Slievebane Group (GSNI 1995).

At Coalisland, the conformable Namurian-Westphalian boundary is equivalent to the contact between the Millstone Grit and the Coal Measures Group (Fowler & Robbie 1961; Fig. 18.2, Col. 6; Fig. 18.3). Black mudstones of the Coalisland Marine Band at the base of the latter group ⁺⁸ contain the definitive ammonoid *Gastrioceras subcrenatum*. Succeeding strata include workable coals and non-marine bivalve faunas of the *Lenisulcata* and *Communis* chronozones. The boundary between the two chronozones is placed at a *Lingula* band above the Beltiboy Coal (Ramsbottom *et al.* 1978).

Fig. 18.1. Geological map showing the distribution of Carboniferous strata in Northern Ireland, adapted from GSNI (1997).

Fig. 18.2. Correlation of Carboniferous successions in Northern Ireland. Details are adapted from the following publications: Col. 1 from Brandon & Hodson (1984) and Legg *et al.* (1998); Col. 2 from Mitchell (1995); Col. 3 from GSNI (1982) and Mitchell & Mitchell (1983); Col. 4 from Mitchell & Owens (1990) and GSNI (1994; 1995); Col. 5 from GSNI (1984), Somerville *et al.* (2001) and Cózar *et al.* (2005); Col. 6 from Robbie (1955), GSNI (1960), Cameron & Old (1997), Somerville (1999) and Cózar *et al.* (2005); Col. 7 from Bazley *et al.* (1997) and Cameron & Old (1997); Col. 8 from Wilson & Robbie (1966), Griffith & Wilson (1982), Geraghty (1997) and Smith *et al.* (1991).

Fig. 18.3 Correlation of Westphalian strata for Northern Ireland and Ireland, showing named coals, sandstones and marine bands. Compiled from Ramsbottom *et al.* (1978) and Sevastopulo (2001).

