Ireland is virtually encircled by sedimentary basins (Fig. 1) that developed in response to a series of rift episodes interspersed with periods of thermal subsidence. A number of inversion episodes also played a role in the development of sediment source areas and in the structuring of the basins.

These basins can be categorized into two groups. The first comprises the basins of Northern Ireland, the Irish Sea and Celtic Sea areas, and the inboard basins (Slyne, Erris and Donegal basins) of the Atlantic margin. They generally have a NE-SW elongate morphology and typically lie within 100 km of the shore. Their sedimentary fill is predominantly of pre-Tertiary age and they have no major bathymetric expression. The second group, comprising the outboard basins of the Atlantic margin (Goban Spur, Porcupine, Rockall and Hatton basins), lies in deep water. These basins are characterized by having an extensive surface area, typically containing a predominantly Cretaceous and Tertiary succession and having an underfilled sedimentary character.

The Irish offshore basins have been the focus of intermittent phases of exploration since the first well was drilled in 1970. To date, a total of 136 wells has been drilled (Fig. 2), with 37 of these in the basins west of Ireland. The total cost of wells in the Irish offshore, in 2001 prices, is approximately IR£1500 million. A significant amount of 2D reflection seismic data has been acquired (Fig. 3), both as speculative and proprietary surveys. Two commercial gas fields (Kinsale Head and Ballycotton) are currently in production in the North Celtic Sea Basin but are nearing the end of their productive lives. The Corrib gas field in the Slyne Basin is currently undergoing the final stages of appraisal and field development will commence shortly. Some other gas and oil accumulations have been discovered but all of them appear to be relatively small and currently non-commercial to marginally commercial.

Reservoir and source rock horizons have been encountered in the various basins (Croker & Shannon 1995). Most of the drilling to date has concentrated on structural traps (e.g. inversion anticlines and tilted fault blocks) but recent exploration has begun to focus upon a variety of stratigraphic traps (Shannon & Naylor 1998). The results of the exploration in the Irish basins have been generally disappointing. Several phases of exploration drilling in various basins have raised expectations only to see hopes dashed and exploration drilling dwindle for a time before the next phase of optimism and renewed exploration (Naylor 1996). These various phases have been influenced by a variety of factors, such as Ireland’s exploration policy, the oil price, new exploration ideas and advances in drilling and production technology.

Exploration history
Five major periods of exploration have taken place during the past four decades. These blended into one another, reflecting major changes within the international oil industry.

The early era (pre-1973)
The first offshore well (48/25-1), targeted on a shallow Cretaceous prospect in the North Celtic Sea Basin, was spudded in 1970 and encountered gas shows. The following year a second well on this block discovered the Kinsale Head gas field (Colley et al. 1981; Naylor & Shannon 1982; Murray 1995; Taber et al. 1995). Drilling through the 1970s concentrated on shallow inversion structures. The geology of the region was very poorly known, due largely to the poor seismic data quality in the region, and the exploration results were generally disappointing.
The era of oil shortages (1973–83)

The oil crisis of 1973 led to a large increase in oil prices and spurred non-OPEC countries into encouraging exploration for indigenous oil and gas. Major discoveries were made in the UK and Norwegian sectors of the North Sea. New Irish licensing terms, modelled on those applied to the Norwegian offshore, were issued in 1975 and reflected a belief that large fields awaited discovery in the Irish offshore. The terms incorporated the aspiration that the state should benefit by joint ownership of the fields (state participation) and also by the receipt of taxes and royalties. A select number of oil companies were granted acreage under the First Licensing Round in the Fastnet, Porcupine, Slyne, Erris, Donegal and Kish Bank basins and a phase of drilling commenced in 1976. The drilling levels reached a peak in 1978 when 15 wells were drilled (Fig. 2).

The oil crisis of 1979 served to renew exploration interest in the Irish offshore. Improved seismic acquisition techniques revealed deep, unexplored fault block structures at Jurassic level within the North Celtic Sea and Porcupine basins. The Second Licensing Round took place in 1981 and resulted in the entry of a large number of new companies to the Irish offshore. During the following years an ‘open door’ licensing policy was followed, whereby interested companies could either licence open acreage, or take a ‘seismic option’ for a fixed period on such acreage.

The era of economic recession (1983–93)

By c.1983 the effects of the oil price rises of the 1970s had taken a toll on the industrial countries and economic recession had begun to bite. The demand for oil and gas dropped and the oil industry began to turn away from the perceived high risk, unproven regions. While some discoveries were made (MacDonald et al. 1987; Shannon 1993a,b; Caston 1995), there was little evidence of large accumulations. In contrast to other countries the Irish fiscal terms looked...
unattractive, especially for marginal fields which were now regarded as the likely outcome in Irish acreage. The uptake of acreage in the Third Licensing Round of 1984 was low. Over the course of the next few years the Irish terms were modified several times in order to make them more attractive. Eventually the state participation and royalty components were abolished. The Licensing Terms of 1992 offered attractive tax incentives for exploration and production.

The era of Atlantic margin optimism (1993–9)

By the early 1990s exploration had slowed down in most of the Irish basins. The majority of the obvious structures in relatively shallow water had been drilled and the results had been generally disappointing. One exception was the discovery of the Ballycotton gas field, a small accumulation located close to the Kinsale Head gas field. Some exploration interest remained in the Kish Bank and Central Irish Sea basins. However, exploration in the UK and Norwegian parts of the Atlantic margin had provided encouraging results, and this region became an exploration ‘hot spot’. New seismic data in the Slyne, Erris and Rockall basins added to the encouragement and indicated the presence of interesting structures and potential plays. The First Frontier Licensing Round in Irish waters in 1994 was very successful and brought the return of several companies who had previously left Irish waters, together with a number of new companies. The new frontier licensing terms afforded a relatively long lead time to companies before a decision was required to drill or drop acreage. The Second Frontier Licensing Round in 1995 offered blocks in the northern part of the Porcupine Basin and was again heavily subscribed. The Third Frontier Licensing Round of 1997 offered deep water blocks in the Rockall and Erris Basins and was also successful in terms of the acreage licensed. A novel aspect of this round was the instigation of the Petroleum Infrastructure Programme (PIP) whereby the licencees jointly contributed to funding research related to the Rockall region, largely in Irish academic and service institutions. Drilling during the period took place in the Kish Bank Basin and in the shallower waters of the Slyne Basin, with the latter drilling leading to the discovery of the Corrib gas field.

The present and the future (1999 onwards)

The Fourth Frontier Licensing Round, in the southern Porcupine Basin, took place in 1999 but only two exploration groups were awarded
Fig. 3. Annual 2D seismic acquisition (km), offshore Ireland.

acreage. At the time of the announcement of the round the optimistic exploration air of the industry still prevailed. However, by the time the round closed for bidding, major changes in the nature and confidence of the industry had occurred. The results of appraisal drilling on the Connamara oil accumulation in the Porcupine Basin were disappointing. The oil price had dropped significantly. ‘Merger mania’ was in full swing, with a resultant re-focus on finding giant fields by the enlarged companies. There was an increasing interest in more attractive and prolific deep water margins and a number of companies began to feel an overexposure to the high risk, deep water Irish Atlantic margin.

The undoubted highlight of the last 5 years has been the discovery of the Corrib gas field in the Slyne Basin with the drilling of well 18/20-1 in 1996. Appraisal wells have been drilled and successfully tested. Well 18/20-2Z, drilled in 1998, tested gas from a Triassic reservoir at a stabilized flow rate of up to 64 MMSCFD. This is very timely, with the anticipated depletion of the Kinsale Head Field within the next few years. Nevertheless, efforts to prolong the life of the Kinsale Head gas field have continued in recent years, with incremental reserves now being produced through existing facilities. This additional production is the result of a successful re-evaluation of the SW Kinsale extension which culminated in the sub-sea completion and tieback of well 48/25-3 in 1999.

This development of Ireland’s gas resources has occurred against the background of a buoyant indigenous energy market, fuelled by the burgeoning appetite of the ‘Celtic Tiger’ economy. Published forecasts predict that local demand for natural gas could triple by 2005. It is anticipated that further exploration for gas will be stimulated in this environment.

Presently there is little active exploration taking place in the Central Irish Sea and Kish Bank basins. Some exploration activity is anticipated in the south coast basins during the next couple of years with drilling expected in the North Celtic Sea and Fastnet basins. The main focus of exploration activity is currently in the basins west of Ireland – the Porcupine, Slyne, Erris and Rockall basins. Although the potential of the Irish frontier basins is still generally recognized by the industry, Ireland is at a disadvantage in having relatively unproven deep water plays. However, one or more commercial discoveries in the next couple of years could help revitalize exploration confidence.

Despite the relative lack of discoveries there are encouraging prospects, especially for the
basins west of Ireland (Shannon et al. 1995; Spencer et al. 1999; Walsh et al. 1999). A number of gas and oil prospects remain in the Celtic Sea basins at various levels but any discoveries are likely to be small. Some remaining (mostly gas) prospects exist in the Central Irish Sea and the Kish Bank basins (Shannon & Naylor 1998). A number of rift episodes, important in the generation of oil- and gas-bearing structures, are recognized or suggested in all the basins west of Ireland and are comparable to those in other regions of the Atlantic margin. Jurassic source rocks are proven in some of the basins and can be speculated with moderate confidence in others. Structural and stratigraphic traps have been identified at various levels. However, there is very little control on the age or structure of the pre-Tertiary succession in the Rockall Basin, due to a combination of lack of wells and of the seismic masking effect of extensive shallow sills in the basin. In particular, the presence, extent and nature of Jurassic and older strata are uncertain. The unknown nature of source and reservoir rocks in the Rockall Basin, and the lack of information on likely reservoirs in the southern Porcupine Basin, represent major exploration risks (Shannon & Spencer 1999). The structural complexity of the Slyne and Erris basins, together with the problem of seismic data quality, represent the major challenges in this region.

The level of licensing in the Irish offshore remains encouragingly high at the time of writing (early 2001). A total of 104 blocks or part blocks (97 to the west, 7 in the basins to the south of Ireland) are held under 21 licences. Some 33 blocks/part blocks (14 to the south, 15 in the basins to the west) are held under 11 licensing options. A total of 5 blocks/part blocks in the North Celtic Sea Basin are held under petroleum leases. Fourteen blocks are held under licence options in basins to the south of Ireland, while 15 blocks are held under licence options in the west coast basins.

The recent exploration of Ireland’s offshore basins has taken place in the context of rapid technological change. During the past decade, significant advances have occurred in the area of floating production systems, sub-sea completion technology and the acquisition, processing and visualization of 3D seismic data. Although the volume of acquisition is increasing, there has been a limited employment of 3D technology in exploration programmes in the Irish offshore basins (Fig. 4). For example, the present paltry coverage (<2500 km²) within the Porcupine Basin compares most unfavourably with the almost blanket 3D coverage (>15000 km²) of the Faroe–Shetland Basin.
This volume

The 27 papers presented in this thematic volume provide a significant amount of new information on the structural and stratigraphic evolution, thermal history, petroleum systems and reservoir geology of Ireland's offshore basins. The volume provides a companion to the 1995 Geological Society Special Publication (No. 93) which elucidated the petroleum geology of the Irish offshore. The papers in the present volume focus largely upon the petroleum exploration of the region and indicate exploration thinking and results. While the papers cover a broad spectrum of topics and areas, some common themes are identified. In addition, they highlight a number of issues that need to be addressed in order to reduce exploration risk in these basins.

1. All of the offshore Late Palaeozoic to Cenozoic basins have experienced a multi-phase extensional and inversion history. Several rifting episodes are recognized or inferred in a number of these basins: Permo-Triassic, Middle to Late Jurassic and Early to middle Cretaceous. At least two periods of pervasive exhumation are interpreted, one during the Late Carboniferous to Late Permian and one during the Tertiary. Regional uplift and erosion is also interpreted for the Early to middle Cretaceous period. Seismic-stratigraphic analysis of the Paleogene, Neogene and Quaternary sediments of the Atlantic margin basins offers an eloquent testimony to the interlinkage between pulsed sedimentation and the uplift and denudation of inboard regions during the Cenozoic.

2. Petroleum systems are proven or possible in all of the basins. However, the impact of regional exhumation upon the pre-existing petroleum systems within Ireland's offshore basins remains to be fully evaluated. Initial studies from the Irish Sea basins indicate that this can have a radical effect on the source rocks, reservoirs, seal integrity, trap morphology and hydrocarbon displacement patterns within the basins.

3. Geochemical studies of oils and shales suggest that the Lower and Middle Jurassic shales have considerable potential as effective oil-prone source rocks, where preserved in these offshore basins. Oil shows have been typed to Lower Jurassic shales in the Slyne, North Celtic Sea and St George's Channel basins. Biomarker evidence suggests that Middle Jurassic sources have contributed to the hydrocarbon budget in the Porcupine Basin, in addition to the hydrocarbon charge provided by the Upper Jurassic Kimmeridge Clay Formation equivalents. However, our understanding of the Jurassic-sourced petroleum systems requires better constraints on the distribution of individual source rock units within each of the basins. Constraining the timing of maturation and the hydrocarbon drainage pattern from these source units also remains a significant challenge. The source rock potential of the Atlantic margin outboard basins is largely unknown and continues to be a significant exploration risk factor in these basins.

4. The thermal evolution of these sedimentary basins is poorly constrained. Evidence from vitrinite reflectance (VR), apatite fission track analysis (AFTA) and fluid inclusion data suggests that advective heat transfer by hydrodynamic systems occurred during the development of these basins, and may be responsible for both long and short duration heating events recorded by these palaeotemperature indicators. Interestingly, VR data do not record a regionally elevated basal heat flux coincident with Paleogene igneous activity in Atlantic margin basins.

5. The presence, quality and maturation history of Carboniferous source rocks is an issue of concern with respect to the Irish Sea basins. Speculative palaeogeographical reconstructions suggest that the Namurian Holywell Shale, the prolific oil and gas source in the East Irish Sea Basin, may be present in the Kish Bank Basin but was never deposited in the Central Irish Sea area.

6. While there has been a significant amount of speculation on the likely age, facies and hydrocarbon habitat of the pre-Neogene succession in the Rockall Basin, there is very little direct geological information on these aspects. Likewise, the nature of the succession in the southern Porcupine Basin remains conjectural until wells are drilled.

7. Some of the Irish Atlantic margin basins are characterized by extensive, near-surface Tertiary lava flows, igneous dykes and sills. Signal penetration beneath this near-surface high velocity layer is a particular problem due to a variable morphology, a heterogeneous velocity structure and the absorption of P- and
S-wave energy. The application of 3D seismic technology, combined with low-frequency acquisition, judicious multiple attenuation and velocity picking offers a way forward to improved sub-basalt imaging in this environment.

8. The Neogene and Recent successions in the Atlantic margin basins contain evidence for major changes in oceanic current circulation patterns, sediment transport, slope development and mass failure features. Exciting evidence for the growth of carbonate mound clusters, and their possible linkage with gas escape features, is coming to light. These features are likely to present opportunities for fruitful study into aspects of climate change in late Neogene to Recent times, demonstrating that there are significant scientific research offshoots of the exploration effort in Ireland’s offshore basins.

These themes reflect some of the questions being addressed by explorationists and others working in Ireland’s offshore basins. This present volume is not intended to present the definitive statement on the petroleum geology of these basins, but rather to present a snapshot of current understanding which will hopefully provide a stimulus for new ideas and a template for further exploration. The quest to understand the Irish offshore basins and their hydrocarbon habitat continues.

This volume arose from the proceedings of a two-day conference held in Dublin in April 1999. The conference was organized by the Department of the Marine and Natural Resources, the Institute of Petroleum and the Irish Offshore Operators’ Association. We would like to take this opportunity to thank the members of the PEIOB conference organizing committee – Peter Croker, Pat Shannon and Geirr Haarr, whose collective energies ensured that the conference was a successful and enjoyable event. In producing this volume we are indebted to a large number of individuals and organizations: the authors who gave freely of their time and expertise to produce these papers, and the companies, universities and institutions who permitted publication. Finally, we wish to thank all the referees who thoroughly reviewed the initial manuscripts and greatly contributed to the quality of the final papers. They are: Nigel Ainsworth, Philip Allen, Morten Sparre Andersen, Ray Archer, Ken Baxter, Chris Bean, Doug Boyd, Richard Bray, Andrew Brock, Glen Caley, Tim Chapman, Geoff Clayton, Dermot Corcoran, John Conroy, Peter Croker, Bryan Cronin, Alex Densmore, Ian Duncan, Robin Dyer, Richard England, Martin Feely, Delwyn Geraghty, Ken Glennie, Paul Green, Paul Griffiths, Adrian Hartley, Stuart Haszeldine, Geir Ulveit Haugen, Peter Haughton, Steve Hay, Amy Heath, Ken Higgs, Deepak Inamdar, Sarah Johnston, Gareth Jones, Steve Jones, Jan Sverre Laberg, Xiang-Yang Li, Brian MacTiernan, Angela McDonnell, Neil Meadows, John Moore, Noel Murphy, Dave Naylor, Phil Newman, Brian O’Reilly, John O’Sullivan, Adrian Phillips, Daniel Praeg, Peter Readman, Jonathan Redfern, Dave Roberts, Adrian Robinson, Pat Shannon, Iain Sinclair, George Sevastopulo, Steve Smith, Mike Stephenson, Dave Tappin, Michael Tate, Alastair Thomson, Vikram Unnithan, Anne Walsh, Tjeerd van Weering, Andy Wheeler. Thanks are also due to Peter Croker and Michael Hanrahan of the Petroleum Affairs Division, Department of the Marine and Natural Resources, for providing the data for Figures 2-4.

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