Final Report

AN ASSESSMENT OF THE CURRENT STATUS AND RTDI REQUIREMENTS IN RESPECT OF THE DEVELOPMENT OF IRISH SEABED RESOURCES

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Table of Contents

List of Appendices .................................................................................................................. 6
List of Figures .......................................................................................................................... 7
List of Tables ........................................................................................................................... 8
Executive Summary ................................................................................................................. 9

Offshore Oil and Gas .................................................................................................................. 9
Current status of Ireland’s offshore hydrocarbons industry .......................................................... 9
Principal support Agencies ......................................................................................................... 9
State Agencies ............................................................................................................................ 9
Non State Agencies .................................................................................................................. 12
RTDI Opportunities associated with offshore oil and gas ............................................................. 12
Research and Development ....................................................................................................... 12
E&P Technology and engineering .............................................................................................. 12
Environmental RTDI .................................................................................................................. 12
Metocean RTDI .......................................................................................................................... 13
Logistics ...................................................................................................................................... 13

Aggregates .................................................................................................................................. 14
Extent of resources ....................................................................................................................... 14
Recoverability of aggregate resources ....................................................................................... 14
Environmental issues associated with the extraction of marine aggregates ................................ 14
Management of resources .......................................................................................................... 15
RTDI Associated with aggregate resources .................................................................................. 16

Other minerals ........................................................................................................................... 17
Orthogenic phosphate ............................................................................................................... 17
Methane - Hydrate (Clathrate) .................................................................................................... 17

Carbonate mounds ..................................................................................................................... 18
Future RTDI opportunities are envisaged in the following thematic areas: .................................... 19
Outlook ....................................................................................................................................... 19

Heavy Mineral Sands ................................................................................................................ 20
RTDI Potential ............................................................................................................................ 20

Metalliferous nodules and crusts ............................................................................................... 21
Maërl ........................................................................................................................................... 21

1 Terms of Reference .................................................................................................................. 23

2 Offshore Hydrocarbons Sector ................................................................................................ 25

2.1 Current status of the offshore hydrocarbons sector ................................................................ 25
2.1.1 Introduction ...................................................................................................................... 25
2.1.2 Geological Perspective of Ireland’s Oil Province: General Distribution of Resources .......... 27
2.1.2.1 Irish Sea basins ........................................................................................................... 27
2.1.2.2 Celtic Sea Basins ....................................................................................................... 30
2.1.2.3 Frontier basins ......................................................................................................... 30
2.1.3 Economic and commercial factors affecting hydrocarbon resource exploitation in Ireland ........................................................................................................ 31
2.1.4 Current licensing situation in Ireland ................................................................................ 32
2.1.5 Pivotal developments: The Corrib Field .......................................................................... 33

2.2 Summary review of role and capabilities of the principal support industries and agencies ........ 33
2.2.1 General introduction ....................................................................................................... 33
2.2.2 Introduction to State Support Agencies ......................................................................... 34
2.2.3 Roles and capabilities of Petroleum Affairs Division (PAD) ........................................... 35
2.2.3.1 Petroleum Affairs Division (Administrative and Technical) ....................................... 35
2.2.3.2 Petroleum Infrastructure Program Organisation ......................................................... 36
2.2.3.3 Offshore Support Group (OSG) .................................................................................. 36
2.2.3.5 Porcupine Studies Group (PSG) .................................................................................. 39
2.2.4. Enterprise Ireland ......................................................................................................... 40

Current Status and RTDI Requirements in Respect of the Development of Irish Seabed Resources
2.3 Scope of RTDI Opportunities Associated with the Offshore Oil and Gas Sector

3 Aggregates

3.1 Extent of Aggregate Resources

3.2 Factors Affecting Recoverability of Aggregate Resources

3.3 Environmental Issues Associated with Aggregate Resources
3.4 Resource Management ........................................................................................................ 97
  3.4.1 Legislative and institutional management framework ...................................................... 98
  3.4.1.1 Status of official licensing policy and procedures .......................................................... 99
  3.4.1.2 Standardisation of application procedures and EIA criteria ......................................... 99
  3.4.2 Options for policing monitoring and management ............................................................ 100
    3.4.2.1 Electronic monitoring systems (EMS) ......................................................................... 100
      EMS as part of the UK aggregate management strategy ....................................................... 101
      EMS equipment .................................................................................................................. 101
      Operation of the EMS ........................................................................................................ 101
      Output from the EMS .......................................................................................................... 101
      Costs of EMS ..................................................................................................................... 103
    3.4.2.2 Synthesis of current extent and recoverability of methane hydrates in Irish waters ............ 105
    3.4.2.3 RTDI initiatives ........................................................................................................... 125
    3.4.2.3.1 Hydrate research in Irish waters ............................................................................... 125
    3.4.2.3.2 Hydrates in pipelines ............................................................................................... 126
    3.4.2.3.3 Examples of international Hydrate research ............................................................ 126
  3.4.2.4 UK strategic research priorities .................................................................................... 108
  3.4.3 Marine archaeology ......................................................................................................... 96
  3.4.3.1 Status of official licensing policy and procedures .......................................................... 99
  3.4.3.2 Standardisation of application procedures and EIA criteria ......................................... 99
  3.4.3.3 Examples of international Hydrate research ................................................................. 126
    (a) Case study of Idaho National Engineering and Environmental Laboratory ....................... 126
    (b) Novel hydrate research, special applications in clathrate technology. ................................ 127
  3.4.3.3 Summary of Hydrate related RTDI issues in the Irish context ........................................ 129

4. Other minerals .................................................................................................................... 114

4.1 Orthogenic Phosphate ...................................................................................................... 114
  4.1.1 Current international experience with respect to the exploration and development of orthogenic phosphate resources ................................................................. 114
  4.1.2 Synthesis of extent and recoverability of orthogenic phosphate in Irish waters .................. 114
  4.1.3 RTDI initiatives associated with orthogenic phosphate ................................................... 115

4.2 Methane - Hydrate (Clathrate) .......................................................................................... 116
  4.2.1 Current international experience with respect to the exploration and development of methane-hydrate resources .................................................................................. 116
    4.2.1.1 Formation and occurrence of methane hydrates ......................................................... 116
    4.2.1.2 Methane hydrates as an energy source ....................................................................... 120
    4.2.1.3 International research initiatives ............................................................................... 120
    4.2.1.4 Extraction of methane ............................................................................................... 121
    4.2.1.5 Links with climate .................................................................................................... 122
    4.2.1.6 Sediment stability .................................................................................................... 122
  4.2.2 Synthesis of current extent and recoverability of methane hydrates in Irish waters ............ 123
    4.2.2.1 Potential distribution of gas hydrates in Irish waters .................................................... 123
    4.2.2.2 Prospects of economic recovery of hydrates from Irish waters .................................... 125
  4.2.3 RTDI initiatives ............................................................................................................. 125
    4.2.3.1 Hydrate research in Irish waters ............................................................................... 125
    4.2.3.2 Hydrates in pipelines ............................................................................................... 126
    4.2.3.3 Examples of international Hydrate research .............................................................. 126
      (a) Case study of Idaho National Engineering and Environmental Laboratory ....................... 126
      (b) Novel hydrate research, special applications in clathrate technology. ................................ 127
    4.2.3.3 Summary of Hydrate related RTDI issues in the Irish context ........................................ 129

4.3 Carbonate Mounds ........................................................................................................... 130
4.3.1 Current international experience with respect to the exploration and development of carbonate mound resources

4.3.1.1 Formation and occurrence of carbonate mounds ................................................................. 130
4.3.1.2 International research initiatives ..................................................................................... 132
   (a) Ecomound .......................................................................................................................... 132
   (b) ACES – Atlantic Coral Ecosystem Study ............................................................................. 133
   (c) Geomound ........................................................................................................................ 134
   (d) Associated studies ............................................................................................................ 135

4.3.2. Synthesis of current extent and recoverability of coral mounds in Irish waters .................. 136

4.3.3. RTDI initiatives .............................................................................................................. 138
   4.3.3.1 Introduction .................................................................................................................. 138
   4.3.3.2 Potential carbonate mound related project themes ......................................................... 138
   4.3.3.3 Outlook for carbonate mound linked research: summary of limitations and opportunities .. 141

4.4 Heavy Mineral Sands ...................................................................................................... 142

4.4.1 Current international experience with respect to the exploration and development of heavy mineral sand resources ...................................................... 142
   4.4.1.1 Characteristics and formation of placer deposits ............................................................ 142
   4.4.1.2 World distribution of placers ........................................................................................ 142
   4.4.1.3 Mineral types and principal mining operations .............................................................. 143
       Diamond .............................................................................................................................. 143
       Gold and platinum .............................................................................................................. 143
       Titanium .............................................................................................................................. 143
       Tin ....................................................................................................................................... 144

4.4.2 Synthesis of the current extent and recoverability of heavy mineral sands in Irish waters ....... 145
   4.4.2.1 Mineral sands in Co.Wicklow ....................................................................................... 146
   4.4.2.2 Mineral sands in Co.Wicklow ....................................................................................... 146

4.4.3 RTDI initiatives associated with placer mineral deposits .................................................. 148
   4.4.3.1 Induced Polarisation (IP) .............................................................................................. 148

4.5 Metalliferous Nodules and Crusts .................................................................................. 152

4.5.1 Current international experience with respect to the exploration and development of metalliferous nodule and crust resources ........................................................................ 152
   4.5.1.1 Characteristics and formation of metalliferous deposits ............................................... 152
   4.5.1.2 Polymetallic nodules .................................................................................................... 152
   4.5.1.3 Metalliferous crusts ...................................................................................................... 160
   4.5.1.4 Polymetallic sulphide deposits ...................................................................................... 161

4.5.2 Synthesis of the current extent and recoverability of metalliferous nodules and crusts in Irish waters ................................................................................................. 163
   4.5.3 RTDI initiatives .............................................................................................................. 163

4.6 Maërîl .............................................................................................................................. 166

4.6.1 Current international experience with respect to the exploration and development of maërîl resources ......................................................... 166
   4.6.1.1 Characteristics and formation of maërîl deposits ............................................................ 166
   4.6.2 Synthesis of their current extent and recoverability in Irish waters .................................. 167
   4.6.3 RTDI initiatives.............................................................................................................. 167

Appendices .................................................................................................................................. 170
References ................................................................................................................................... 233
URLs ........................................................................................................................................... 242
List of Appendices

Appendix I USGS Re-assessment of world petroleum resources.

Appendix II Irish Offshore Operators Association

Appendix III Acreage position for petroleum exploration and development offshore Ireland

Appendix IV Minutes of meeting held at PAD, Wed 1st Dec 1999.

Appendix V Summary of projects approved for funding under RSG PIP.

Appendix VI Details of statutory instruments of the Health and Safety Authority

Appendix VII Current applications in underwater robotics

Appendix VIII Data sources from CRC sand and gravel database

Appendix IX Extract from Munster Express

Appendix X Draft guidance on EIA in relation to dredging applications in English waters

Appendix XI US Dept of Energy national methane hydrate multi-year R&D plan

Appendix XII *Personal communication* from Michael Max re: Gas hydrate R&D
List of Figures

Figure 2.1 The world sub-sea market-trends (Westwood & Associates, 1999).
Figure 2.2 The distribution and locations of the major offshore sedimentary basins.
Figure 2.3 Structure of the PIP
Figure 2.4 Structure of the Rockall studies group
Figure 2.5.1 Summary diagram showing structure of various groups and activities under the Auspices of Dept of Public Enterprise
Figure 2.5.2 Summary diagram showing structure of various groups and activities under the Auspices of Dept of Public Enterprise
Figure 2.5.3 Summary diagram showing structure of various groups and activities under the Auspices of Dept of the Marine and Natural Resources
Figure 2.5.4 Summary diagram showing structure of various groups and activities under the Auspices of Dept of the Marine and Natural Resources
Figure 3.1 East coast from Dundalk to Wicklow.
Figure 3.2 East and south east coasts from Wicklow to Youghal.
Figure 3.4 West coast from north county Clare to north of Galway bay.
Figure 3.5 West coast from Clew bay to Blacksod bay.
Figure 3.6 North west coast from Blacksod bay to Malin head.
Figure 3.7 Time/effort 3 dimensional representation of dredging activity
Figure 4.1 Phase boundary diagram of gas-hydrate stability field for fresh water
Figure 4.2 Position of the hydrate stability zone in the upper sediment
Figure 4.3 Seismic section of the Blake ridge showing BSR
Figure 4.4 Potential distribution of methane hydrates in Irish waters
Figure 4.5 Distribution of Coral mounds in Irish waters
Figure 4.6 World distribution of heavy mineral sand deposits
Figure 4.7 Ilmenite (FeTiO$_3$) detected in samples off the East Coast of the United States
Figure 4.8 Locations of Irish heavy mineral sand prospects
Figure 4.9 Schematic diagram of marine induced-polarisation
Figure 4.10 An example of marine induced-polarisation data
Figure 5.1 World-wide distribution of manganese nodules
Figure 5.2 Cross section of a manganese nodule
Figure 5.3 Example of nodule harvesting device in the form of a benthic crawler
Figure 5.4 Distribution of Maërl beds in Irish waters

List of Tables

Table 2.1 Volumes of undiscovered world petroleum, by commodity
Table 2.2 Results of survey of support companies
Table 2.2.1 Summary extract from the offshore oil and gas register
Table 4.1 Mineral sand compositions
Table 4.2 Main characteristics of three recognised nodule containing seabed facies
Table 4.3 Summary of Consortia that have been involved in manganese nodule exploration
Executive Summary

Introduction
The principal aim of this work is to identify and detail themes and projects that offer current and future potential for RTDI associated with Irish seabed resources. This objective has been approached through a stepwise method whereby the various hard and soft seabed resources have been divided into three basic categories (oil and gas, aggregates, others), and then individually described under a common set of headings. Intensive literature searches were undertaken, and the opinions of a number of internationally and nationally recognised authorities sought in order to provide a current and scientifically firm basis for the recommendations that are presented.

Offshore Oil and Gas

Current status of Ireland’s offshore hydrocarbons industry
Ireland’s offshore hydrocarbons are regarded by the transnational extractive industry as high risk in a marginal frontier province. The course of development of Irish offshore hydrocarbon resources has been sporadic. Following the initial high uptake of exploration licenses that accompanied the first round in 1975, activity and interest waned. The amendment of fiscal terms and reallocation of risk in the 1993 Frontier licensing round was followed by a period of increased activity during which the Corrib field was discovered. These favourable licensing terms help greatly to sustain the current levels of investment in Exploration and Production (E&P). Despite the very high probability of the arrival onshore of gas from the Corrib field, the industry has indicated that at least one further commercial discovery will be required during the coming year to ensure that activity is sufficient to sustain the domestic suppliers of goods and services (IOAA, 1999). Thus, the survival of these indigenous industries may be reliant on optimising competitiveness and seeking alternative markets. Although exploration effort expended in the Irish offshore province has not been very successful to date, the geological prospectus indicates that considerable potential for discovery remains in the western frontier deepwater basins, as well as in the Irish Sea, and Celtic Sea basins (Shannon, 1996).

During the last 18 months, the price of oil has risen sharply and stabilised at c. 150% above its level in early 1999. World fuel requirements primarily for transport are set to grow 50% by the year 2020. Substantial buoyancy is evident in the international subsea industry, with anticipated peak expenditure expected to reach $20 billion by 2004. It is not yet clear what direct impact these factors will have on E&P nationally, however, taken together they convey a cautious note of optimism. In reality, the main value of this improved outlook may be realised through enhanced opportunities for Irish researchers and developers of goods and services on the international stage.

Principal support Agencies.

State Agencies
All matters of principal relevance to the offshore industry in Irish waters are administered on a continual basis by the Petroleum Affairs Division of the Department of the Marine and Natural Resources (PAD), who are closely supported by the Offshore and Coastal Engineering Unit of Enterprise Ireland and the Health and Safety Authority. The role of the PAD is to maximise the benefit to the state from E&P of indigenous oil and gas resources, whilst ensuring that activities are conducted safely and with due regard to their impact on the
environment and other land/sea users. A second tier of state agencies, *i.e.* Marine Institute, Coast Guard, Met Eireann, Geological Survey of Ireland, Fire Service, FÁS, Commissioners of Irish Lights, Environmental Protection Agency and the Irish Aviation Authority, provide expertise as well as direct and indirect services in support of the primary agencies when required. Additional downstream activities in relation to refining, transmission and distribution, are the long-term responsibility of the Irish National Petroleum Corporation Ltd., and Bord Gáis Eireann. The roles and responsibilities of main state agencies in relation to offshore oil and gas activities are summarised in table A.
<table>
<thead>
<tr>
<th>Agency</th>
<th>Government Department</th>
<th>Principal Role/Responsibility/Strategy</th>
<th>Subdivision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Affairs Division</td>
<td>DOMNR</td>
<td>Continental-shelf jurisdiction, licensing, maximising opportunities for indigenous support industries and research and data gathering, optimise future exploration effort.</td>
<td>PIP-OSG, RSG, PSG,</td>
</tr>
<tr>
<td>Enterprise Ireland-Offshore and Coastal Engineering Unit</td>
<td>Enterprise Trade &amp; Employment</td>
<td>Offshore certification, Industrial linkage, Offshore engineering consultancy, coastal engineering,</td>
<td></td>
</tr>
<tr>
<td>Health and Safety Authority</td>
<td>Enterprise Trade &amp; Employment</td>
<td>Administration of health and safety at work, monitoring of compliance with codes of practice and legislation, research and training</td>
<td></td>
</tr>
<tr>
<td>Marine Institute</td>
<td>DOMNR</td>
<td>Promotion and coordination of marine research, technical support and specialist engineering services, marine data.</td>
<td>FRC-discharge issues</td>
</tr>
<tr>
<td>Coast Guard</td>
<td>DOMNR</td>
<td>Coordination of marine rescue, emergency and pollution response services.</td>
<td></td>
</tr>
<tr>
<td>Met Eireann</td>
<td>Public Enterprise</td>
<td>Weather services and marine climatological database</td>
<td></td>
</tr>
<tr>
<td>Geological Survey of Ireland</td>
<td>Enterprise Trade &amp; Employment</td>
<td>Collection and interpretation of marine geological data</td>
<td></td>
</tr>
<tr>
<td>Fire Service</td>
<td>Local Authorities</td>
<td>Fire-fighting training for offshore industry</td>
<td></td>
</tr>
<tr>
<td>FÁS-Training and Employment Authority</td>
<td>Enterprise Trade &amp; Employment</td>
<td>Personnel safety certification</td>
<td></td>
</tr>
<tr>
<td>Commissioners of Irish Lights</td>
<td>Public Enterprise</td>
<td>Aids to navigation re offshore installations, instructions to surveyors</td>
<td></td>
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<td>Environmental Protection Agency</td>
<td>Environment</td>
<td>Pollution monitoring</td>
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<td>Marine Survey Office</td>
<td>DOMNR</td>
<td>Vessel safety certification</td>
<td></td>
</tr>
<tr>
<td>Irish Aviation Authority</td>
<td>Public Enterprise</td>
<td>Advisory information on helicopter handling at offshore installations</td>
<td></td>
</tr>
</tbody>
</table>
Non State Agencies

There were at least 124 companies listed in the Enterprise Ireland Oil and Gas Register for 2000. Thirty eight separate business categories are represented supplying a broad spectrum of services and material goods to the offshore industry in Ireland and in a few cases overseas. Liaison between these businesses, and the companies representing the offshore industry is focused through the Irish Offshore Operators Association who also liase with government departments on behalf of its members.

RTDI Opportunities associated with offshore oil and gas

A number of opportunities for the development of innovative research and development projects have been identified. These have been selected in accordance with perceived international and national (National Development Plan) RTDI priorities, as well as those identified through the Marine Institute’s own SWOT analyses of the broader Irish Marine Technology sector. Close co-operation between the Marine Institute, PAD and Enterprise Ireland will ensure that future MI initiatives are optimally integrated with, and complement, existing industrially partnered programs such as the Petroleum Infrastructure Program (PIP). Major proposals have been tabled for the establishment of an Integrated Ocean Management Plan (Anthony Grehan, MRI, 2000, *personal communication*), and for the foundation of a centre dedicated to research in this field. These are seen as positive developments that in accordance with similar initiatives internationally should provide a coherent framework within which complex jurisdictional, resource and scientific research management decisions can more effectively be made.

Research and Development

The following is a short summary of hydrocarbon related RTDI themes that are detailed in section 2.3. of this report.

E&P Technology and engineering

- Components and control systems for ROVs and AUVs, including innovative manipulators and tooling, power systems and cost reduction.
- Development of SCADA and other innovatory systems for electronic supervisory control and data acquisition across a range of applications.
- Support and continued development of existing areas of expertise such as riser technology, design of offshore structures and geotechnical support services.
- Materials research.

Environmental RTDI

- Seabed and near seabed processes including geological assessments and geotechnical characteristics in relation to engineering constraints.
- Biologically related components of seabed systems including micro- and macrofauna, importance of methanogenic bacterial systems, carbonate mounds and gas hydrates.
- Environmental impact of OOG&E&P activities, EIAs, long-term monitoring programs, toxic discharges.
- Cetaceans and seabirds monitoring, baseline mapping and allied research.
- Examination of potential effects on fisheries.
- Enhancements and developments to coastal sensitivity index initiatives, data capture and software development.
Metocean RTDI
- Support and development and add-on to existing research under Petroleum Infrastructure Program, and joint industry programs e.g. Shamrock.
- Deployment of oceanographic instrumentation, multiple sensors.
- Development of new and innovative sensor and instrumentation packages and enhancements to existing systems.
- Derivatives and enhancements to existing hydrodynamic models for dispersion and operational prediction. Coastal sensitivity indices.

Logistics
- Survey design and implementation-hydrographic, acoustic, environmental.
- Policy studies concerning development of strategic planning initiatives for EZ monitoring and management.
- Logistical co-ordination and assessment of potential for further and enhanced technical co-operation and sponsorship between industry, academia and state bodies.
- Drilling project logistical management.
- Safety case preparation.
Aggregates

Extent of resources
Available geological information indicates the presence of extensive deposits of marine aggregates around the Irish coast within the 50m depth operational range of conventional dredging equipment. The general distribution of sands and gravels around the Irish coast is portrayed in a series of six charts (section 3.1) each of which are accompanied by a summary describing the nature of deposits in each region. Although detailed resource appraisals are lacking for many areas, attention is currently focused on the extractive potential of Holocene deposits that exist off the east and south east coasts. Several extractions yielding material of good quality have been successfully carried out during the last decade for strategic or once-off projects, and the case for licensing fully commercial extraction is currently under review at the Department of the Marine.

Recoverability of aggregate resources
Diverse logistical, financial and environmental factors affect the recoverability of marine aggregates. It is noted that many of the factors outlined below also apply in relation to seabed resources of other types as described in section 4.

The main logistical and administrative factors:
- Depth of water above deposits (40-50m is the practical limit of economic recovery)
- Presence of overburden material
- Site metocean conditions, particularly wave climate
- Protracted licensing and environmental impact statement procedures
- Potential conflicts of use e.g. fisheries feeding and spawning grounds, offshore windfarms, shipping lanes and harbour approaches, sites containing items of national heritage or other special scientific interest

The main economic factors:
- Landing and cargo-handling costs
- Distance to market for low value high bulk cargo
- Cost of exploration; baseline geological information-resource appraisals, unresolved scope of environmental impact investigations
- Costs of recovery through dredging, high spatial variability in quality of deposit material and thus requirements for on-board or on-shore processing
- Market forces and distribution of regional demand

Environmental issues associated with the extraction of marine aggregates
The location of aggregate deposits coincides with other legitimate uses of the coastal zone, principally fisheries. Research over the last two decades has shown that removal of material from the seabed will impact directly and indirectly on many biological, sedimentary and water column systems. Many of these effects have been quantified through international research efforts and a considerable body of work is now available for reference, particularly in the form of reports based on commissioned or focused research. Of particular note in this regard are the annual reports of ICES WGEXT\(^1\). These reports comprehensively document

\(^1\) International Council for the Exploration of the Sea-Marine Habitat Committee-Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem.
the evolution of current international consensus in relation to aggregate extraction issues, national regional geological mapping initiatives and the development of policies and codes of practice. The principal impacts on environmental resources to emerge from these and other studies are summarised below. Readers are encouraged to refer to the main text for detailed explanations of interactions and underlying processes, including temporal and spatial extents.

- Significant alteration of seabed terrain can result. Depending on the dredging technique being employed this ranges from shallow furrows (hopper suction) to deep pits (static clamshell). Infilling of these features in partly predictable but dependant on local tidal conditions and sediment composition. Changes in the resultant sediment structure can be detrimental. Documented effects including development of anoxic conditions, and significant differences in post-dredge benthic community structure have been documented. Increases in local tidal velocity can lead to erosion of fine particles, and their subsequent deposition on adjacent banks.
- Effects on biological resources are dependant on the intensity of dredging, the degree of disturbance of sediments, intrinsic reproduction rates, and recolonisation rates of original community members. Reduction in species diversity, numbers of individuals, and community biomass are documented effects.
- Impacts on fin and shellfish derive mainly from increased rates of turbidity generated by draghead friction on the seabed and overspill. Other secondary effects are associated with blanketing effects of subsequently resettled fines, which may smother or inhibit benthic food species.
- These effects can transfer to higher trophic levels and impact on bird or mammal populations.
- Documented physical impacts outside the boundaries of the dredging area are poorly understood and most likely in association with multiply licensed areas, they include: transport and deposition of fines from outwash plumes; impacts on coastal erosion, beach draw down and replenishment processes through interruption of sediment supply pathways.

Environmental issues are determining factors in the planning process. Many researchers have observed that when carefully sited, managed and monitored, extractive activities have substantially less impact than is generally perceived, and that most of the quantifiable effects are localised and of short duration. Recent studies have concentrated on resolving the dynamic complexities of sediment plume formation and dispersion, as well as determining the long-term or cumulative effects of aggregate extraction, particularly in heavily licensed areas. Considerable international research effort is currently being expended in order to optimise the design of mitigative measures to be incorporated in the design of EIAs and best practice guidelines.

**Management of resources**

Resource management issues are currently under serious review for the first time in Ireland but have been evolving continuously in other countries with established marine aggregate industries. Aggregate extraction in Ireland is directly administered principally by the DOMNR\(^1\) under a raft of statutory legislation, (EIA Acts, Foreshore Acts, Continental Shelf Act, Water Pollution Acts, Fisheries Acts, Harbours Act) as well as a number of EU directives that have more general relevance (see section 3.4). Government policy in relation

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\(^1\) Department of the Marine and Natural Resources
to seabed sand and gravel deposits is evolving, and it is not yet clear whether such deposits are clearly recognised as a source of construction material that should be accessible to commercial interests. If commercial extraction is to proceed then a set of strategic management objectives are required upon which guidelines for EIAs, SEIAs (strategic EIAs) and best operational best practice can be based. This process can be informed through detailed reviews of UK and European models which are available through ICES, and EMSAGG, and which incorporate the findings of extensive programs of appropriately targeted research. A number of enabling technologies including Electronic Monitoring Systems and Geographic Information Systems are widely employed to improve efficiency and facilitate the resource management process.

**RTDI Associated with aggregate resources**

- Inauguration of a representative body to act in liaison with MI, relevant statutory and non-statutory bodies, academic and other institutions and public representatives. This body could also provide guidance in the development of strategic policy in key areas of relevance as outlined above.
- Continued and enhanced support for existing areas of research including sedimentological studies, environmental modelling, biotope and seabed mapping, databases, GIS.
- Development of new programs based on Irish and International priorities including establishing standardised management and review procedures, and investigation of cumulative effects.
- Increased involvement in ICES WGEXT and development of networking links and co-operative committees in unison with UK French and other neighbouring countries with interests in the field e.g. through EMSAGG.
- Increased involvement in all EU commission backed research associated with aggregates.
- Detailed investigation of use of innovative techniques for resource evaluation, and the potential for joint industry programs.
- Development of detailed package of priorities with respect to potential extraction areas in relation to established conservation strategies, establishment of buffer zones.
- Research and development of suite of monitoring protocols and sensors.
- Development of higher resolution hydrodynamic models leading to improved predictive capacity and better understanding of coastal systems.
Other minerals

The final section of this report deals with several classes of marine resources, often termed “economic minerals”. Some of these resources e.g. carbonate mounds, mineral placer deposits, have a significant presence in Irish waters and in the case of maërl, commercial exploitation is advanced. The presence of methane hydrate deposits has not been conclusively proven although this cannot be ruled out. Deposits of orthogenic phosphate, and various metallic compounds including manganese nodules and crusts have been reported but are not well documented. Each of these resource types has been described according to a format which firstly presents a descriptive account set in the context of international experience of exploration and development; progresses to an account of what is known of the resource in Irish waters, and concludes with a summary of themes and projects that are considered to hold RTDI potential.

Orthogenic phosphate

Abundant phosphate bearing compounds are found as sedimentary deposits mainly associated with areas of high biological production in low and mid latitudes. Most existing deposits date from the Miocene when conditions favourable for deposition were widespread. Although highly valued as fertiliser, abundant terrestrial supplies mean that extensive commercial exploitation of phosphates is very limited at the present time. Potentially economic deposits that have been located off the coasts of North Carolina, Florida (USA), and the Chatham Islands (NZ) are likely to be the first to be mined in the future. Marine phosphate deposits have been investigated in Ireland. These are thought to be derived from reworked onshore sediments, and although details are lacking, are unlikely to constitute a significant resource. There would appear to be little incentive to undertake significant RTDI initiatives in association with phosphates at the present time, although the existence of the Co Clare deposits is flagged for inclusion should future geological investigations be carried out in the vicinity.

Methane - Hydrate (Clathrate)

Methane hydrates have been cited as being the fuel of the future. Existing in the form of an ice-like crystalline solid matrix, hydrates or clathrate contains $158\text{cm}^3$ of methane per $\text{cm}^3$. Extensive deposits are found globally in continental shelf margin marine sediments, and terrestrially under permafrost. Biogenic and thermogenic processes give rise to deposits that differ considerably in concentration and density of occurrence within host sediments. Methane hydrates have importance beyond their fuel resource potential, and many nations have implemented extensive strategic research programs, most notably in the US, Russia, India and Japan. These programs are examining a wide range of hydrate related issues among which the following are of high priority:

- Improving detection methods for resource characterisation
- Developing safe and efficient production techniques
- Exploring links with climate and the global carbon cycle
- Sediment stability and geohazard potential
• Special applications in clathrate technology

The physical conditions, in terms of temperature and pressure, exist at the Irish shelf break and deeper sediments suitable for hydrates stability, however, despite extensive seismic profiling, conclusive evidence of BSRs\(^1\) indicating the presence of a significant hydrate layer have not been shown to date. This lack of evidence may be a function of the techniques that have heretofore been employed in conducting and interpreting seismic investigations, since these are focused on locating much deeper oil and gas reservoir structures. In any event, it is considered rather unlikely that hydrates from Irish waters will be regarded as an economically extractable resource for the foreseeable future.

In reviewing related topics with RTDI potential a view can been taken that extends beyond the lack of immediate resource potential and considers the wider significance of hydrates. In this perspective, the following may be considered, although it is acknowledged that there is very little Irish involvement in hydrate research to date:

• Opportunities for innovative engineering and design solutions to problems associated with spontaneous hydrate formation in pipelines
• Reinterpretation of existing seismic records, and specific inclusion of hydrate oriented prospecting in the design of future acoustic surveys.
• Research into the role of past or present hydrate layers in slope stability and sediment processes in relation to assessment of geohazard for oil and gas installations, pipelines and submarine cables.
• Research into linkages between hydrates and methane as a greenhouse gas in relation to past present and future climate changes.
• Other specialist or niche areas associated with novel applications in clathrate technology such as synthetic fuel media, desalination techniques, marine construction materials, and exotic bacterial enzyme systems.

**Carbonate mounds**

Carbonate mounds are uniquely significant in scientific terms, and the documented existence of several hundred in Irish waters has provided, since their formal recognition in the early 1990s, a potent focus for international research measures. Although documented from margins in Australian and Norwegian waters, mounds in the Irish domain are particularly well developed. Ranging in width at the base between 100m and 1800m, and rising to a maximum of 350m above the surrounding seabed, mounds occur in several main groups in water depths between 500m and 1000m on continental slopes. A complex range of interacting processes is thought to be involved in mound formation and morphological control. Two main hypotheses respectively propose: linkages with hydrocarbon seepage from below, and external environmental related forcing in combination with the geological setting. Samples and recent imagery indicate the presence of highly developed ecosystems built around species of ahermatypic coral (*Lophelia pertusa* and *Madrepora oculata*). In contrast to many of the other resource types presented in this study, research on carbonate mounds is well established with representation from several Irish institutions (e.g. UCC, NUIG, and UCD) working in collaboration with leading European field specialists on EU funded programs. These interlinked multidisciplinary projects (outlined in summary below)

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\(^1\) Bottom simulating reflectors which are indicators of the presence of hydrate layers in seismic records.
provide a state-of-the-art overview of mound related issues extending beyond Irish waters, and constitute a robust platform upon which future national and international research programs will be based.

**Ecomound**
Aims to define the principal environmental controls and processes involved in the development and distribution of carbonate mounds in the NW European continental margin.

**ACES – Atlantic Coral Ecosystem Study**
Aims to provide a margin-wide environmental baseline assessment of the status of Europe’s deep water coral margin with recommendations for essential monitoring and methodology requirements for future sustainable development.

**Geomound**
Aims to explore the coincidence of large provinces of carbonate mounds with actively explored hydrocarbon basins, and the frequent association with surface expressions of fluid flow. It will investigate their significance in relation to evaluation of fluid related slope

**Associated studies**
Outside inherent interactions between these projects, co-operative linkages exist with Deep-Bug, COSTA and STATAGEM. Associated studies to emerge recently include:
- CARACOLE involving ROV investigations of carbonate mounds in the Porcupine and Rockall basins.
- Proposal to Oceanic Drilling Program to drill the base of a carbonate mound
- Deployment of TOBI and BRIDGET for surveys in the Porcupine Seabight and Rockall Trough (part funding for shiptime being sought)
- Proposal to develop the “Deep-Reef Surveyor” towed survey platform

**Future RTDI opportunities are envisaged in the following thematic areas:**

- Mapping all of the mounds in Irish waters both in terms of their specific locations, morphological variability (hence elucidating controls), construction and composition
- Provision of a detailed inventory of the biology of all of the mounds and examine inter-mound and intra-mounds biological variation
- An assessment of the role that carbonate mounds play with respect to fish nurseries
- Effects of current fishing practices in the vicinity of carbonate mounds
- Assessment of role and potential of carbonate mound associated chemosynthetic bacteria
- Investigation and development of high resolution climatic signals from carbonate mounds and investigation of the impacts upon and relationships with existing climatic models
- Suite of studies of current flow and other oceanographic parameters through a program of extensive field measurements and refinement of existing flow and oceanographic models

**Outlook**
Carbonate mounds offer a spectacular showcase of international importance to the development of new deep-water technologies where rigorous testing can occur and impressive, aesthetic, eye-catching images can be obtained to facilitate better marketing and
stimulate further investment. Never before has there existed such an opportunity to capitalise on international interest in cooperation and assistance for Irish deep-sea research. Suitable technologies are needed to facilitate exploration of deep-water carbonate mound resources, these include: digital video and camera systems, high resolution deep-tow seismic and sidescan sonar systems, and AUVs, as well as coring and sampling equipment.

**Heavy Mineral Sands**

Sandy deposits containing heavy minerals and mineral compounds are found as placer deposits on continental shelves worldwide, from the beach to the outer shelf. Valuable commodities including gold, diamonds, platinum, tin, chromite, iron-sand, zircon, ilmenite, rutile and monazite have all been mined commercially from such deposits. The diamond operations off South Africa and Namibia are billion dollar enterprises requiring innovative recovery techniques that involve the deployment of high-tech underwater mining bulldozers. Very large deposits of high value commodities including gold, platinum and titanium have been located and exploited in the past e.g. at Nome in Alaska, although currently uneconomic owing to unfavourable world markets. Internationally important quantities of tin are produced from offshore placers in Malaysia, Indonesia, Thailand, Bolivia and Brazil, whilst multiple billion dollar deposits are known to exist in Alaska, Russia, Burma, China, and the Philippines. Tin, as with other strategic minerals, is subject to commodity price fluctuations linked to variability in world markets, and is currently in a period of oversupply.

As far as can be ascertained there is currently little interest in Irish placer deposits, although joint industry GSI reconnaissance surveys during the 1980s identified several potentially viable deposits. The main areas of interest were north west Donegal, Mayo and south of Wicklow head on the east coast. Although beach sands of Brittas Bay were found to contain potentially commercial amounts of rutile, magnetite, chromite, zircon, sphene, epidote, chlorite and staurolite; no extraction was carried out owing to environmental concerns. It should be noted that many of the environmental issues applying to the extraction of aggregates hold equally for mineral placers.

**RTDI Potential**

It is likely that development of mineral placer prospecting initiatives in Ireland will be dependant on world market prices. However there may be opportunities to apply, adapt and improve technologies such as Induced Polarisation, with a view to discovery of new resources. International research is focused mainly on:

- Improvements in resource prospecting; discovery, mapping, quantification and characterisation
- Improvements in recovery techniques
- Mitigation of environmental effects

Recent work in Ireland has focused on the use of heavy mineral signatures to trace sediment transport and provenance pathways from catchments to offshore. Sedimentary petrologic analyses for scientific and economic objectives are highly skilled and extremely labour intensive, thus there may be potential to investigate ways to automate laboratory procedures and streamline analytical protocols with the use of innovative techniques.
Mtalleriferous nodules and crusts

The two main classes of deep sea metalliferous minerals are: a) Metalliferous oxides including manganese nodules (found at depths of 5000m lying on the seabed) and cobalt crusts (thin encrustations on rock between 800 and 2400m usually on seamount flanks), and b) polymetallic sulphides which are associated with vulcanicity, usually mid ocean ridge spreading centres and island arc systems. They respectively contain significant quantities of manganese, copper, nickel, iron, zinc and lead as well as trace amounts of precious metals in some cases. All are formed by complex, and as yet poorly understood, processes of precipitation. They are found in large quantities both in international waters and within national EEZ limits, and have been subject to heavy commercial investment aimed principally at resource discovery, quantification and in the development of recovery techniques. Progress to the exploitation phase is, however, subject to market forces, and although enormous reserves of manganese nodules have been located and quantified, it is the extensive loosely consolidated polymetallic sulphide deposits of the Red Sea that currently offer the best prospect for recovery.

Examples of these resource types are known mostly from anecdotal evidence within Irish waters, although this situation may change in coming years as basic oceanic research and mapping programs gather momentum. RTDI initiatives are likely to stem from the ongoing need to improve techniques for substrate type or sediment facies discrimination. Collaboration with overseas institutions will be important in order to optimise entry into acoustic research programs at an appropriate level. Other opportunities may arise in the application of existing metallurgical expertise to improve extraction and refining techniques, particularly, if significant resources are discovered. Improvements in the design of benthic sampling equipment for groundtruthing are always required.

Maërl

Maërl, a Breton term describes accumulations fine to medium course sediments that are formed from the exoskeletons of various species of slow growing (c.876 gm\(^{-2}\text{yr}^{-1}\)) coralline algae. Found globally in coastal waters but best known from Atlantic France and Ireland, maërl deposits have been exploited for many centuries, principally in Brittany as a source of calcium carbonate for use as a soil additive. More recently maërl has been extracted at rates of 600,000 tonnes yr\(^{-1}\) from French waters (1991), 30,000 tonnes yr\(^{-1}\) from the Fal Estuary in the UK (1975-1991), and currently 8,000 tonnes yr\(^{-1}\) from Castletownbere in Ireland. The list of uses for maërl and its by-products now encompasses the following: soil amelioration, agricultural and horticultural fertiliser, animal fodder additive, acid water treatment, biological de-nitrification, drinking-water potabilization, toxin elimination, as well as use in the pharmaceutical, cosmetics, nuclear and medical industries. The importance of maërl as a high diversity marine habitat has been highlighted in recent years, and is now recognised through the inclusion of the main deposit forming species on International habits lists, as deserving management and protection.

Maërl beds are found extensively around the west coast of Ireland, although the majority of confirmed deposits are concentrated in the waters of Galway, Cork and Kerry. Recent survey
work published by the Marine Institute\textsuperscript{1} gives speculative estimates for the national resource in the order of 3million m$^3$. Commercial extraction is currently licensed only to the Celtic Sea Minerals company who extract at the rate of 120 tonnes d$^{-1}$ for onshore processing and packaging, for subsequent marketing of a number of branded products.

Research is currently focused on many aspects of basic maërl biology, and studies on growth rates of bed forming species under varying environmental conditions are considered to be a priority in relation to the development of resource management protocols. Further development of the commercial industry is dependant on identification of innovative uses, products and marketing strategies in the face of overseas competition.

\textsuperscript{1} A study of selected maërl beds in Irish waters and their potential for sustainable extraction. De Grave \textit{et al.}, 2000)
1 Terms of Reference

This report has been prepared in fulfilment of a Marine Institute research contract entitled:

*An Assessment of the current status and RTDI requirements in respect of the development of Irish Seabed Resources*

It has been prepared by the CRC research team who have delivered all elements defined in the terms of reference as set out below:

- An assessment of the current status of the offshore hydrocarbons sector in Ireland with a summary review of the role and capabilities of the principal support industries and agencies, and identification of the scope of RTDI opportunities for Irish researchers in this context.

- A synthesis of current knowledge of the extent and potential recoverability of marine aggregates, identification of environmental and resource management issues associated with their extraction, and the scope of RTDI to address deficiencies in these areas.

- A description of current international experience in respect to the exploration and development of other marine minerals, a synthesis of current knowledge of their extent and recoverability in Irish waters, and the outlining of RTDI initiatives to address deficiencies in our understanding of these resources.

Qualification of terms of reference:

During preliminary meetings with Marine Institute representatives, additional information was supplied to the research team. This information clarified the objectives of the work that was to supply information pertinent to MI requirements in relation to establishing a national research framework, and in particular to highlight seabed resource related RTDI themes that may be usefully considered for funding under the terms of forthcoming Marine Research Measures.

The report is structured into three main sections corresponding to the main categories of seabed resources as follows:

- Offshore Oil and Gas
- Sand and Gravel
- Other Resources

In each case the main characteristics are presented in logical sequence that begins with a general descriptive account of the resource, moving on to an account of its distribution in
Irish territorial waters. Practical considerations pertinent to utilisation of the resource, citing international experience, are then presented accordingly. In the light of these introductory elements, each section then draws out key themes that in the view of the team represent realistic prospects for Research Technology Development and Innovation in the near medium and longer term. Appropriate detailed actions and research themes are offered, and where possible these are further developed into concepts for potential projects.
2 Offshore Hydrocarbons Sector

2.1 Current status of the offshore hydrocarbons sector

2.1.1 Introduction

In compiling this overview of the current status of the Irish offshore hydrocarbons sector it has been necessary to examine a diverse range of published material from many sources. The picture that is presented in section two has been assembled from these generally fragmentary and occasionally conflicting accounts, as well as the personal opinions of a number of national and international authorities.

During the course of the work, every attempt has been made to obtain and present a full, meaningful and balanced appraisal by means of cross-field consultation. However, it is widely recognised that this is a highly competitive commercial sector, dominated by large and aggressive multinational corporations, and where there are few constants - except change. Consequently commentators often avoid definitive statements, in favour of providing generalised analyses of the dominant trends, particularly in relation to future activities. Although this somewhat speculative approach is a general characteristic of world Exploration and Production (E&P) market commentary, it is particularly manifest in an Irish context. This is due mainly to the uncertain nature of the Irish hydrocarbon province, the rigors of commercial confidentiality, and the extent to which Ireland's attractiveness is dependent on external economic factors, particularly the price of oil on the world market.

Currently oil is at its highest value since the early 1990's having rapidly risen from an historic low of around $10 per barrel in early 1999 to above $35 per barrel in recent months. Currently standing at around $25 on foot of recent OPEC agreements on production levels, this is still significantly above last years prices, although long-term price stability is still an issue.

A realistic assessment of the status of Irish offshore hydrocarbons cannot be achieved in isolation from the world stage, and thus this work begins by setting Irish resources in an international context. Popular current consensus states that the international sub-sea industry is at the start of a considerable upswing. This is illustrated in Fig. 2.1 taken from 'The World Deepwater Report 2000-2004' (Westwood, 1999a). This graph shows past and projected expenditure in the world deepwater oil and gas market with an anticipated peak of $20 billion by 2004. The IEA (International Energy Authority) has forecast that the demand for oil world-wide is set to grow by 50% by 2020, a primary driver for which being the increase in use of transportation fuel.

However, whilst the global view is very positive beyond expectations made in 1998, the portion of this growth assigned to Europe as a whole is more modest for the following main reasons (Westwood, 1999a):

"Most future activity is sited in the ‘golden triangle’ of Brazil, West Africa and the Gulf of Mexico. The study shows that some of the greatest of these prospects lie off..."
West Africa with projects including the $2.5 billion Girassol field located on Block 17 off Angola. Over the next 5 years the authors expect West African deepwater expenditure to accelerate from about $800 million in 2000, to nearly $5.5 billion in 2004, possible even eclipsing Brazil to become the world’s largest deepwater market."

Figure 2.1 The world sub-sea market-trends (Westwood & Associates, 1999)

![Graph showing the world sub-sea market-trends from 1995 to 2004 with data points for North America, Middle East, Latin America, Europe, Australasia, Asia, and Africa.]

The general trends outlined in both of the reports discussed above can be placed in the context of the findings of a second important study, further details of which are given in Appendix I. This recent publication of the US Geological Survey (USGS, 2000) assesses the volume of hydrocarbons that can be added to the world reserves in the next 30 years (see table 2.1) The study deals with world oil reserves according to a scheme of geological provinces, for which detailed individual analyses have been prepared, the province containing information on Ireland is not yet complete but is next in line and eventually be made available on CD ROM at some time in the future.

Table 2.1 Volumes of undiscovered world petroleum, by commodity, from this assessment (mean values, exclusive of the United States) and the previous USGS assessment

<table>
<thead>
<tr>
<th>Commodity</th>
<th>USGS 1993 Assessment</th>
<th>USGS 2000 Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undiscovered oil</td>
<td>539 billion barrels</td>
<td>649 billion barrels</td>
</tr>
<tr>
<td>Undiscovered natural gas</td>
<td>915 BBOE (^1)</td>
<td>778 BBOE</td>
</tr>
<tr>
<td>Undiscovered natural gas liquids</td>
<td>90 BBOE</td>
<td>207 BBOE</td>
</tr>
<tr>
<td>World Total</td>
<td>1544 BBOE</td>
<td>1634 BBOE</td>
</tr>
</tbody>
</table>

\(^1\)BBOE = billion barrels of oil equivalent
High operating costs are a chief factor in tempering interest in European and Irish reserves. Within the European context Ireland’s deepwater province is directly comparable with the successful and geologically similar fields of Foinaven, Schiehallion, and Stronsay fields of the West Shetland region in UK waters. Consensus would indicate that the main bulk of North Sea hydrocarbon reserves have been located and are, or will, soon be under exploitation. Future prospects for new/large North Sea discoveries are slim, with most activity focused on optimising extraction of existing smaller, linked and satellite reservoirs by means of extended and directional drilling programs. Thus European-wide exploratory focus is moving towards the deepwater prospective zones. One consequence of this strategy is that many existing platform and sub-sea installations are likely to see extended service beyond forecast operational longevity, and will thus require extensive programs of detailed structural checking and maintenance (see section 2.3.4.1).

**2.1.2 Geological Perspective of Ireland’s Oil Province: General Distribution of Resources**

Geological conditions favourable to the upward migration and subsequent (relatively) near-surface entrapment of hydrocarbons (petroleum plays) are found extensively throughout the Irish geological province, both on and offshore. There is a wide range of plays, only some of which have been drilled and tested, and many of the offshore plays remain to be drilled. The offshore basins can be divided into three groups, Irish Sea, Celtic Sea, and Frontier basins. A review by Shannon (1996) gives a comprehensive background and detailed outline of the geological features and processes that give rise to oil and gas reservoirs in each of these regions, set in the context of offshore exploration. The following is a brief summary providing a geological context in terms of structures and rock formations to which the hydrocarbon resources in Irish waters owe their origin and which characterise the prospectivity of the region.

The major sedimentary basins that surround Ireland have their origin in the Late Palaeozoic to early Cenozoic. They formed during the break-up of the Pangaeon supercontinent, as a general east-west extensional domain of the newly developing oceanic crust to the west of Ireland. The distribution and locations of the major offshore sedimentary basins are shown in Figure 2.2.

**2.1.2.1 Irish Sea basins**

These lie in shallow water (<100m) and comprise of the Kish and Central Irish Sea basins. The deformed basement rocks are similar to those exposed onshore along the Irish east coast and are Lower Palaeozoic, overlain locally by Visean limestones. The overlying geological scenario is similar to that of the eastern Irish Sea, which has considerable oil and gas reserves. Petroleum plays in the Irish sector of this region have been drilled (11 wells to 1997) with encouraging source rock formations but no shows to date (2000). It is considered that this region is relatively under-explored, as drilling has been peripheral to the main basin. Some potential exists for gas plays in the Kish Bank and Central Irish Sea basins. Fairly recent investigatory work (Croker, 1995; Croker & Power, 1996; Croker & Power, 1997) has been focused on sites in the Irish Sea, which are believed to be active gas seeps. Some insights of significance to the hydrocarbons exploration industry are presented (Croker, 1995) that propose a coalbed or thermogenic origin for this methane gas in the Carboniferous deposits underlying the region. The later reconnaissance site investigations include the Western Trench, Central Trench, and Kish Bank Anomaly. These investigations
have recorded sonar, seismic and photographic images of many interesting superficial geological and biological features including cemented crusts and tubeworm colonies. Drilling results of structural traps (tilted fault blocks or 4-way dip-closed) have been encouraging in terms of sedimentary succession, but have produced no hydrocarbon shows. Whilst there are speculative reasons for the latter, including the risk of a lack of source rocks, there would appear to be several potentially promising plays that may warrant further exploratory drilling in the future as the region is still considered to be under-explored.
Figure 2.2 The distribution and locations of the major offshore sedimentary basins and petroleum license blocks. Source PAD

CONCESSION MAP

Authorisations current in JANUARY 2000

LEASES

LICENCES

ONSHORE PPL

OPTIONS

PETROLREIM AFFAIRS DIVISION
2.1.2.2 Celtic Sea Basins

These basins lie to the south of Ireland and have ENE-WSW to NE-SW orientation. The basins are generally inter-linked and divided into two parallel series by a discontinuous basement ridge. The Fastnet, North Celtic Sea and St George's Channel basins lie to the north of the ridge with the Cockburn, South Celtic Sea and Bristol Channel basins. Water depths range from 100m in the east to 200m in the Fastnet basin. The orientation of the basins is controlled by Caledonian (Devonian) and Variscan (Carboniferous) structures, upon which there is a succession of up to 9 km of sedimentary rocks. Of the c.80 wells drilled in these basins, 15 have flowed oil or gas others had shows only. The gas that is being produced originates in Greensand Formation (formed in the shallow-marine) and Wealdon sandstone reservoirs (formed in shore-face or fluvial conditions). Most of the other reservoir rocks are various sandstones ranging down to the Lower Jurassic. The Kinsale Head and Ballycotton gas fields are facing exhaustion within the next 2-4 years. Of the remaining flows Helvick Head and Seven Heads fields have the most potential but are currently uneconomic (see section 2.1.3). Discussion of results of drilling various traps indicates several reasons for the lack of further success in these basins. These include structural complexity, breaching of structures, and biodegradation of oil due to freshwater flushing. There is also considerable potential in undrilled stratigraphic and tilted fault block traps. This view was given added support with the gas discovery in UK waters of the St. George’s Channel basin (Block 103/1), with its origin in mature gas prone Jurassic source rock. This area has subsequently been subject to renewal of interest stimulated by the extent of geological continuity across to the Irish sector of the basin. The western basins of Fastnet and Coburn, and the South Celtic Sea Basin, are considered as offering less potential, though reservoirs may be present, there is a risk of a lack of regionally mature source rocks, though the presence of dramatic halokinetic and other sedimentary structures offers some positive indications.

2.1.2.3 Frontier basins

These basins lie to the west, south west and north west of Ireland, and are generally in deep water of >1000m and have a NE to SW orientation. They include the Porcupine Basin, the Goban Spur, the NW offshore basins (Slyne, Erris, and Donegal) the basins of the Rockall region (Rockall, Hatton and Hatton margin). Up to 1996 many of these areas had experienced very little exploration, and consequently their geology was not well understood, with the exception of the Porcupine, where significant numbers of wells had been sunk and sediment thicknesses of >10km are preserved. This compares with Rockall where 6km of sediments are preserved and 3km of sediment in the northern basins of the Goban Spur. In the last few years, considerable amounts of seismic data have been collected over the entire continental margin and it is likely that this will have added significantly to an understanding of the regional geology. The Rockall Trough basin region has recently been the subject of a detailed study (Naylor, Shannon & Murphy, 1999) under the auspices of the Petroleum Affairs Division of the Department of the Marine and Natural Resources (PAD) that deals with the structure and nomenclature of the region. Source rock and reservoir potential is offered in the Upper Carboniferous rocks encountered through drilling in the Porcupine Erris and Donegal basins. The bulk of exploratory effort in these basins has been targeted on tilted fault block structures, with varying levels of success. Good quality oil (35-45 API) and gas has been tested from the Porcupine, and the Northern basins have produced some shows, as well as the only other potentially commercial gas reservoir discovered in Irish waters to date. Source rocks for gas in this area are in the Upper Carboniferous, with oil source rocks in the
Lower Jurassic. A large variety of source and reservoir rocks are posited to exist throughout this entire frontier region with a complex range of (as yet often speculative) structural and sedimentary scenarios. Detailed treatment is considered beyond the scope of this summary, however there would appear little doubt that significant potential remains to be explored, with specific focus being drawn to the tilted fault blocks in the Slyne, Erris, and Rockall Trough basins with abundant Jurassic reservoir rocks.

2.1.3 Economic and commercial factors affecting hydrocarbon resource exploitation in Ireland

This section traces the evolution of the Irish offshore industry through the main exploratory milestones that have occurred since the commencement of activity in 1975. It also explores some issues relating to the contribution of offshore oil and gas exploitation to the Irish economy, and its evolution under changing fiscal and economic conditions.

Ireland’s offshore hydrocarbon resources are regarded by the industry as being high risk. The fact that they are in frontier deep-water, and are to date commercially unsuccessful must be placed in the context of long term depressed oil prices, and an industry that is only recently showing signs of an active recovery. Oil companies are also in a period of consolidation and merger, which reduces the number of operators willing and able to tackle high-risk prospects (IOAA, 1999). Taken in combination, these factors generate a bleak outlook for future activity in the sector. However, consideration of available geological appraisals tends to support the view that there is sufficient (theoretical) potential in the longer term for more commercial finds to be made, and thus to sustain the interest of the industry for a considerable period hence.

The Irish Offshore Operators Association\(^1\) commissioned an economic assessment of the contribution of Irish oil and gas exploration and production operations to the Irish economy, which was published in Nov. 1999. This document offers some important insight into the industry from an operator’s point of view, and the following points succinctly document the main milestones during the industry’s development in Ireland over the last couple of decades:

- The first licensing round was introduced by the Irish Government in 1975 and produced good take-up and led to further rounds in 1982 and 1985, although response to the later rounds was much less enthusiastic.
- Up to 1978, 34 wells had been drilled in total, the bulk of these in the Celtic and Fastnet basins. 1978 saw the start of more emphasis on the Porcupine Basin although wells were still being sunk in the Celtic basins.
- Between 1989 and 1995 only 22 wells were drilled, all of these in the Celtic or Irish Sea basins.
- Up to 1989, 101 wells are recorded (PAD public release data, 1997) some 30 of these had been drilled off the west coast, some with hydrocarbon traces, none commercial. The Connemara Field being the most promising (originally discovered by BP in the late 1970's). Two test production wells, later sunk by Statoil in 1995 were abandoned after a month owing to poor results.

\(^1\) Formed 1995, the IOAA is an association of, and representative organisation for oil and gas companies having an active interest in Ireland. Further details are set out in Appendix II.
Frontier licensing rounds were begun in 1993, since when the majority of new licenses have been awarded in the Atlantic Margin part of the Irish Continental shelf, off the west coast. Fiscal terms were amended (abolition of state participation and royalties, and special tax conditions) for this round with a shift in risk allocation.

Between 1993 and 1995, 21 licenses were awarded to different operators. Of these 8 remain active, and since 1993, 9 wells have been drilled including 2 development wells in the Connenmar Field, and two appraisal wells in the Corrib Field. The Corrib Field discovery (1996) by Enterprise Oil is the most significant result.

A further four commitment wells remain to be drilled in these frontier licenses, but more wells may be drilled depending on results. It is possible that most of the 1993-1995 licenses could be relinquished by the end of 2001 if results are poor.

Whilst there is little current drilling activity off the east and south coasts, the potential development of some existing discoveries is under active review.

In 1997 a further 11 licenses were awarded in the Irish Rockall Trough. Altogether, 15 companies were involved in first truly deep-water licenses (>1000m) and large areas were licensed. As part of the license commitments, abundant seismic data have been acquired, and one of the licenses has a drilling commitment to be completed by the end of 2001.

The 1999, South Porcupine licensing round resulted in only two new licenses being awarded (reflecting volatility and lack of commercial success).

A key factor emerging from this report suggests that viability in terms of the future activity of the E&P sector as a whole is contingent upon the achievement of at least one further commercial discovery in the next two years. Failure in this regard could lead to a reduction to below the limit of sustainability for domestic service and downstream industries, which should thus focus on alternative international markets, and optimising competitiveness.

### 2.1.4 Current licensing situation in Ireland

As of August 1999 the licensing situation with respect to the three main categories is as follows:

- Standard Licenses: 2
- Deepwater Licenses: 1
- Frontier Licenses: 21

Details of individual licensee holdings, and explanatory notes describing the scope and responsibilities that accompany each form of petroleum license, are presented in Appendix III (from the PAD status report showing licensing and acreage position as of 1st August 1999). The issue of licensing terms has obvious and direct implications, not only on the level of offshore activity, but also on the extent of opportunities for involvement of Irish goods and service companies. This was amply reflected in the upswing of activity that followed changes instigated in the 1993 round. Although specific documentary evidence for the direct effects on Irish goods and services companies has not been encountered in this study, the Irish Small to Medium Enterprise Association (ISME) has highlighted the issue and strongly suggests that the matter warrants review.
2.1.5 Pivotal developments: The Corrib Field

As well as being the only successful new find currently under development, the Enterprise Oil Corrib gas field off County Galway has significance with respect to maintaining national strategic supplies in the light of the forecasted end to production from the Kinsale gas fields by 2005.

Enterprise Oil was expected to sink two trial wells during summer 2000, as part of an overall bid to bring gas ashore by 2003. It is understood that this target date has been advanced in order that Corrib gas will replace Kinsale gas in timely fashion and obviate the need for alternative supplies to be sourced from the UK. These arrangements have obvious advantages from the point of view of maintaining Ireland’s independence of supply, with Bord Gáis extending the existing supply pipeline infrastructure towards a Mayo landfall. Some preparatory work has already begun and Fugro Geos has carried out preliminary site evaluations and route surveys for a prospective pipeline. This infrastructure development has resulted in a number of calls to tender for the supply of additional goods and services. EIA’s for the landfall of the pipeline and the refinery have been completed and have met some local opposition.

2.2 Summary review of role and capabilities of the principal support industries and agencies

2.2.1 General introduction

The extraction of oil and gas from beneath the sea requires the use of very costly and highly specialised equipment and expertise. Thus the extraction process, particularly from deep water provinces, is in the hands of small number of dedicated operational specialists on contract to multinational corporations. These companies and corporations are, however, reliant upon a diverse range of other (local) industries and supportive expertise to ensure successful and efficient operations on the ground. The process involves exploration and production as well as requirements to maintain environmental standards. The types of expertise involved therefore includes all marine scientific disciplines (especially geology) in the exploration stage, whilst production involves advanced engineering, system design and logistical support. Due to the scale and political стрategic nature of providing an indigenous national fuel supply, policy and legislative support is also involved within state organisations and semi-state companies.

A full summary of the role of state support agencies is presented in the following sections 2.2.2 to 2.2.5. A brief summary review of the non-state industrial support sector is also presented, although in less detail (section 2.2.6), since this sector has recently been the subject of a full and detailed analysis prepared by the marine services division of Enterprise Ireland on behalf of, and in collaboration with, PAD. The evolution of this situation regarding slight overlap in terms of reference is described in Appendix IV where minutes of a meeting between the Marine Institute, Coastal Resources Centre, UCC and PAD are presented.
2.2.2 Introduction to State Support Agencies

The various groups that can be considered as acting in a broadly supporting role to the offshore industry fall into one of three categories: direct roles, supportive roles and downstream roles.

The following three state agencies have a direct and specified role with respect to the affairs of the offshore oil and gas industry:

- Petroleum Affairs Division of the Dept of the Marine and Natural Resources
- Enterprise Ireland-Offshore and Coastal Engineering Unit
- Health and Safety Authority

In addition to these primary agencies that have an ongoing and pro-active brief, the following state agencies operate in a supportive role providing services and intervention as and when the need arises:

- Marine Institute: promotion and co-ordination of marine research.
  1) Technical Support Base.
  2) Irish Marine Data Centre.
- Coast Guard (formerly Irish Marine Emergency Service): marine rescue co-ordination centre and pollution response services.
- Met Eireann: provision of weather services and marine climatological database.
- Geological Survey of Ireland: collection and interpretation of marine geological data.
- Cork City Fire Brigade: fire-fighting training for the offshore industry.
- FÁS Training and Employment Authority: safety certification of offshore personnel in Irish waters.
- Commissioners of Irish Lights: notification of potential hazards to navigation.
- Environmental Protection Agency: pollution monitoring in estuarine and coastal waters.
- Irish Aviation Authority: safety Certification authority for helicopter companies operating offshore.

A third category of state body are involved in downstream activities as follows:

- Irish National Petroleum Corporation Ltd.: state company with responsibility for maintaining Ireland’s strategic reserves of crude oil, and operates the national refinery. The operations are carried out through Irish Refining Plc, and Bantry Terminals Plc.
2.2.3 Roles and capabilities of Petroleum Affairs Division (PAD)

The principal role, schedule of activities and areas of responsibility pertaining to PAD are outlined as follows:

2.2.3.1 Petroleum Affairs Division (Administrative and Technical)

- Principal Officer: Pat Ryan
- Senior Exploration Specialist: Dr. Keith Robinson

The role of the Petroleum Affairs Division is to maximise the benefits to the State from exploration for and production of indigenous oil and gas resources, while ensuring that activities are conducted safely and with due regard to their impact on the environment and other land/sea users.

The functions of the Division are carried out through a number of strategies with the following objectives:

- To maximise the area of continental shelf jurisdiction:
  - establish and delineate an undisputed outer limit of the continental shelf.
- To license private enterprise to conduct exploration and production (E&P) under terms which balance the interests of the State and of private enterprise while ensuring that:
  - there is effective and efficient E&P;
  - operations are carried out in accordance with best practices;
  - there is effective liaison with the E&P industry.
- To have the opportunities maximised for Irish business/institutions to service the needs of E&P in Ireland:
  - by facilitating the establishment of a mechanism whereby Irish goods and services get full opportunities to participate in exploration activities offshore Ireland.
- To provide stimuli for medium and long-term exploration efforts in Ireland by:
  - securing Irish E&P industry assistance towards building up the local E&P-related infrastructure;
  - working with the Irish E&P industry to have research and joint industry research and data-gathering carried out.

The Division is responsible for the promotion, regulation and monitoring of the exploration and development of oil and gas in onshore and offshore Ireland. This involves the allocation of acreage to exploration companies under various types of licences, agreeing appropriate work programmes, and the promotion of acreage, either through open access or by a “round system”.

Promotion encompasses the:
- identification of areas with potential;
- preparation of interpretative reports [over such areas];
- encouraging companies to acquire new data in such areas;
- release of basic geological, geophysical and well data to the industry.

Regulation involves:
• agreeing with operators work programmes which are appropriate for the type of authorisation and the area to be licensed while taking account of both the operator's and the State's interests.

Monitoring involves:
• ensuring that agreed work programmes are carried out in accordance with good oilfield practice, having particular regard to safety, the environment and other land/sea users.

2.2.3.2 Petroleum Infrastructure Program Organisation

PAD established the Petroleum Infrastructure Program (PIP) on 4th June 1997 in conjunction with the award of exploration licences under the Rockall Trough Frontier Licensing Round. The administrative structure of the PIP is shown in Figure 2.3.

Figure 2.3 Structure of the PIP.

![Figure 2.3 Structure of the PIP.](image)

The Program currently comprises three Groups funded by all oil companies active in the Rockall Trough and South Porcupine basins with PAD contributing to the funding of one group. The overall aim is to promote hydrocarbon exploration activities in Ireland by strengthening local support structures, funding data gathering and research and by providing a forum for co-operation.

2.2.3.3 Offshore Support Group (OSG)

Aim: To address Ireland’s overall support structure for hydrocarbon exploration and development in the Offshore through industry-related training, equipment purchase and use limited data acquisition research support.

• Funding: £225,000 per annum for four years, 1997-2001
• Participants: Agip, Anadarko, Arco, BG, BP Amoco, British-Borneo, Elf, Enterprise Oil, Mobil, Murphy, Phillips, Saga, Shell, Statoil, Total, Union Texas.
• Management: Administered by the PAD in consultation with the industry and non-commercial interests.
2.2.3.4 Rockall Studies Group (RSG)

Aim: To address common industry problems in the Rockall Trough by:

- Regional data gathering - G&G / geotechnical / environmental / metocean
- Research projects, both applied and academic
- Scholarships associated with the research
- Research cruise sponsorship
- Provision of a forum to facilitate co-operation
- Affording the opportunity for Irish involvement

Funding: £4.8 million (£1.2 million per annum for four years, 1997 - 2001)

Participants: Agip, Anadarko, Arco, BG, BP Amoco, British-Borneo, Elf, Enterprise Oil, Mobil, Murphy, PAD, Phillips, Saga, Shell, Statoil, Total, Union Texas.

Management: Management Committee representing oil companies and PAD (chair)

Secretariat: A Secretariat has been set up in Dublin (CSA Oil & Gas) to assist the RSG with a range of administrative matters including secretarial duties, contract preparation, project management and data storage. Technical committees have been established to cover four technical strands (Figure 2.4) - Subsurface, Seabed, Environment and Metocean - and to define and recommend projects for execution. The technical committees comprise representatives from selected exploration companies and the PAD, but may also draw on outside expertise from time to time. It is the only exploration province in NW Europe where all active companies are involved in a single joint industry program covering geological, geophysical, geotechnical, environmental and metocean data gathering and research. The RSG plans to support projects in all technical strands; the work is intended to include investigation into the nature of pre-Tertiary geology, deep crustal structure, physical / benthic characteristics of the seabed and the predictability of wind, waves and currents. In excess of 60 proposals have been received from a broad spectrum of research organisations and companies and detailed reviews of existing data have been initiated. Work carried out by the RSG is additional to normal licence - specific work programmes and is screened to avoid duplication of effort across national or international boundaries. Co-operation with other joint industry and research groupings is promoted, particularly those focusing on the Atlantic margin frontier area. The work also affords the opportunity for Irish involvement.

Four areas of investigation are each administered by a technical committee:

- Sub Surface: This area covers deep crustal investigations and includes wide angle/OBS (ocean bottom seismometer) seismic acquisition, and gravity/magnetic studies.

- Seabed: This area focuses on all aspects of the sea and near-surface sediments; research activity includes stratigraphic investigation using shallow drilling and slope stability analysis utilising high resolution shallow seismic, sidescan sonar profiling and seabed coring.

- Metocean: A strategy for metocean studies has been prepared to stimulate regional metocean projects.
Environmental: this area of investigation includes seabird and cetacean monitoring, biological and geochemical sampling and benthic studies.

Project Proposals:
Sixty-four project proposals covering the four areas of investigation were received to date (Jun 2000). The technical and management committees reviewed these and twenty-five of the projects were approved. Eleven of those contracts are with organisations based in Ireland. Three data review projects have been completed. The experience obtained and contacts made by Irish personnel will provide a strong basis for winning further business for Ireland in the future. A summary of approved projects is listed in Appendix V. Further information on the Rockall Studies Group is available on the group's website: www.rsg.ie.

Figure 2.4 Structure of the Rockall studies group
2.2.3.5 Porcupine Studies Group (PSG)

The PSG was set up on 15 June 1999 in conjunction with the award of licences under the South Porcupine Frontier Licensing Round.

Aims: To address common industry problems in the Porcupine Basin by:

- Regional data gathering - G&G / geotechnical / environmental / metocean
- Research projects, both applied and Academic
- Scholarships associated with the research
- Research cruise sponsorship
- Provision of a forum to facilitate co-operation
- Affording the opportunity for Irish involvement

Funding: £630k (1999 – 2002) from company members; PAD to contribute £45k towards approved projects.

Participants: Agip, Elf, Chevron, Enterprise Oil, Marathon, Phillips, Statoil, PAD.

Management: Management Committee representing oil companies and PAD (chair)

Secretariat: A Secretariat has been set up in Dublin (CSA Oil and Gas) to assist the PSG with a range of administrative matters including secretarial duties, contract preparation, project management and data storage.

Status current of activities:

Enquiries to the secretariat indicate that the range of activities to be undertaken by this group is broadly similar to that being undertaken by the RSG, and funding has been allocated in the same four main categories: environment, sub-surface, seabed, and metocean. Currently, the PSG isn't quite as evolved as the RSG and a list of the group’s structure remains to been finalised. Detailed listings of projects being undertaken under the PSG are not available at the present time as many are still at the contract negotiation stage. Further details of these may become available through higher channels by direct contact with the group chairman, Mr. Noel Murphy.
2.2.4. Enterprise Ireland

Within the overall organisation of Enterprise Ireland, offshore oil and gas interests are chiefly served Enterprise Ireland’s Offshore, Marine & Coastal Engineering Unit.

Principal officer: Gerard Keane.

Enterprise Ireland’s Offshore, Marine & Coastal Engineering Unit provides a range of services to Ireland’s offshore industry. The Unit has been in existence for over twenty years and has been involved in all major engineering projects offshore Ireland.

Offshore Certification
Enterprise Ireland has a statutory role as the ‘Offshore Certifying Authority’ for Ireland and, as a third party, can certify the design, construction and commissioning of offshore structures, ensuring that they are fit for their intended purpose.

Industrial Linkage
Enterprise Ireland offers advice to companies setting up or those already involved in servicing Ireland’s offshore industry. Areas covered include:

- advice on business opportunities
- advice on sub-contractors and suppliers
- information on standards and specifications
- information on quality requirements

As part of the promotion service provided by Enterprise Ireland, of Irish industry, it maintains the ‘Irish Offshore Oil & Gas Register’ for national and international circulation.

Offshore Engineering Consultancy
Enterprise Ireland carries out the following consultancy services on behalf of clients:

- structure design analysis
- structural fabrication procedures
- offshore and coastal environmental data studies - weather downtime studies
- drilling engineering and well test services

The Offshore, Marine & Coastal Engineering Unit has worked successfully with both government and industry for many years and is well positioned to offer expert advice on the Irish offshore environment and on the requirements of national and international regulations.

Coastal Engineering
Enterprise Ireland’s Offshore & Coastal Engineering Unit provides assistance to engineers, construction companies, local authorities and Government agencies on the design and construction of coastal protection measures and harbour engineering. Services offered include:

- Coastal Environmental Database: an extensive Offshore and Coastal Environmental Database is available containing the most comprehensive data set on offshore and nearshore waves for Ireland.
- Coastal Engineering Project Management: The Unit has extensive experience in managing EU and national coastal engineering projects and has a high success rate with submitted proposals. The Offshore & Coastal Engineering Unit has recently completed the ECOPRO (Environmentally Friendly Coastal Protection) Code of Practice on behalf of the EU Life program. It also has experience of managing national coastal research and technology development projects funded under Government Operational Programmes.

- Wave Refraction / Diffraction Computer Modelling: Enterprise Ireland has in-house wave modelling facilities allowing near-shore wave climates to be examined. Physical modelling of proposed coastal developments can be undertaken in association with local and international hydraulic research institutes.

The following text and block diagrams were supplied by Enterprise Ireland. They summarise the roles and interrelationships of state agencies and with respect to offshore activities.

"The Offshore & Coastal Engineering Unit has worked successfully with both government and industry and is uniquely positioned to offer expert advice on the Irish coastal environment and on the requirement of Irish and EU regulations. Enterprise Ireland, now and in its former constituent parts, since IIRS 1975, has been the common denominator, representing the interests of the State on offshore surveys. Figures 2.5.1; 2.5.2; 2.5.3 & 2.5.4 show the relationships between Enterprise Ireland and other state agencies. Other government departments and agencies will, no doubt, reserve the right to become involved should they see fit."

Fig 2.5.1 Summary diagram showing structure of various groups and activities under the Auspices of Dept of Public Enterprise
Fig 2.5.2 Summary diagram showing structure of various groups and activities under the Auspices of Dept of Enterprise, Trade and Employment

Department of Enterprise, Trade and Employment
Health, Safety and Welfare requirements

Enterprise Ireland
Government nominated
National Certifying Authority:
Rules & Procedures

Health and Safety Authority (HSA)
Note: Legal Authority to shut down an operation

Independent role to issue certification and acceptances. Also acts to ensure other state agency requirements, e.g., HSA, are met, since 1975. Note: International networking with such bodies as HSE, Lloyd’s, ABS, BV, DnV, NMD, NPD, etc., actively pursued to allow a best approach to the tasks in hand over the years, on behalf of the State.

Factories Act, 1955
Dangerous Substances Act, 1972
Safety, Health and Welfare at Work Act, 1989

There are a number of Statutory Instruments related to these regulations dealing with specific activities i.e. handling chemicals etc., a comprehensive list is available from the HSA.

Fig 2.5.3 Summary diagram showing structure of various groups and activities under the auspices of Dept of the marine and natural resources

**Department of the Marine and Natural Resources**

- **Foreshore Acts, 1963 to 1993**
- **Dumping at Sea Act, 1981**
- **Sea Pollution Act, 1991**
- **Maritime Jurisdiction Act, 1959**

- **Irish Marine Emergency Services**
  - Emergency Alertness and Reaction
  - Advice on offshore operations from Enterprise Ireland

- **Fisheries Research Centre**
  - Discharge issues, drilling fluids, etc.
  - Advice from Enterprise Ireland

- **Maritime Safety Division**
  - General Safety Awareness
  - Advice from Enterprise Ireland

- **Petroleum affairs division**
  - Promotion, regulation, and monitoring of offshore E&P.

- **Marine Survey Office (MSO)**
  - Standby Safety Vessels - Certificates of Survey, upon which Letters of Acceptance are issued by Enterprise Ireland
  - Supply Vessels, not requiring Enterprise Ireland involvement
  - Note: The issue of FPSO operations should involve MSO, HSA, Enterprise Ireland

**Note:** Enterprise Ireland, now and in its former constituent parts, since IIRS 1975, has represented the interests of the above on offshore surveys (source: Enterprise Ireland)
Fig 2.5.4 Summary diagram showing structure of various groups and activities under the auspices of Dept of the marine and natural resources

**Department of the Marine and Natural Resources**


**Petroleum Affairs Division**

- Petroleum and Other Minerals Development Act, 1960
- Licencing Terms for Offshore Oil and Gas Exploration and Development, 1992

**Exploration**

- Rules and Procedures for Offshore Petroleum Exploration Operations: Certification managed by Enterprise Ireland:
  - Drill Rig Inspection Report (Enterprise Ireland)

**Production**

- Rules and Procedures for Offshore Petroleum Production Operations: Certification managed by Enterprise Ireland:
  - Preventative Maintenance System Inspection Procedures (Enterprise Ireland)
  - Certificate of Fitness for Purpose (Enterprise Ireland)
  - Standby Boat - Letter of Acceptance (Enterprise Ireland)

**Department of the Environment: Environmental Protection Agency:**

- European Communities (Environmental Impact Assessment) Regulations, 1989

**Environmental Protection Agency:**
- European Communities (Environmental Impact Assessment) Regulations, 1989

**European Communities (Environmental Impact Assessment) Regulations, 1989**

**Current Status and RTDI Requirements in Respect of the Development of Irish Seabed Resources** 44
2.2.5 Health & Safety Authority

The Health and Safety Authority is the national body with overall responsibility for the administration and enforcement of health and safety at work in Ireland. The Authority monitors and enforces compliance with the legislation, provides expert advice to employers and the self-employed and promotes education, training and research. It brings forward, as necessary, proposals for regulations and codes of Practice to the Minister for Enterprise, Trade and Employment. In practice, Enterprise Ireland, (see block diagrams Figures. 2.5.1 to 2.5.4) has undertaken much of the practical implementation of these regulations in relation to offshore activities.

Full texts of the Acts, Orders, Regulations and Codes of Practice, etc. listed here are obtainable from the Government Publications Sales Office.

The following are the Acts of the Oireachtas and Statutory Instruments relating to Occupational Safety and Health and are thus of direct or indirect relevance in the context of offshore activities.

Statutory Instruments:

- 1882 c.22 Boiler Explosions Act, 1882
- 1890 c.35 Boiler Explosions Act, 1890
- No. 10 of 1955 Factories Act
  No. 10 of 1955 & No. 9 of 1980
- No. 7 of 1965 Mines and Quarries Act, 1965
- 1972 European Communities Act, 1972 No. 10 of 1972
- Dangerous Substances Acts, No. 21 of 1979
- Dangerous Substances (Amendment) Act No. 18 of 1987
- Safety, Health and Welfare at Work Act, 1989

Further details of statutory instruments and regulations in this area are given in Appendix VI.
2.2.6 Non-state support industries

As explained in section 2.2.1, this section of the report is dealt with in less depth than other areas and reference is made to Enterprise Ireland (2000). This document was completed during 2000 and may be obtained from the PAD.

The main non-state support organisation is the Irish Offshore Operators Association. Formed in 1995, this group is an umbrella organisation that provides a focal point for liaison between companies participating in Ireland's oil and gas industry and between industry itself, other interested bodies and the relevant government authorities. See Appendix II for a listing of the participating companies. The UK analogue for this group the UKOAA is a highly developed organisation with a clearly defined and active role including RTDI, which can serve as a model for future development of the IOAA. The following categories represent the main support industries utilised by the hydrocarbon sector:

- air freight/courier services
- air travel
- banks
- base services
- casing
- catering
- cement
- chemicals
- clothing and equipment –protective
- communications/navigation equipment
- compressors/generators/engines
- containers/skips/tanks/baskets/compac tors
- design and project management
- diving/ROV contractors
- dredging
- electrical goods
- electric logging
- environmental, pollution, health and safety
- fuel/lubricants
- gas
- geological consultants
- helicopters
- insurance
- laboratories
- labour
- lifting equipment
- lighting
- marine-consultants/client representation
- offshore certification
- paint
- photography
- ropes
- steel fabrication/precision engineering/engineering services/NDE tools/fire equipment/training
- valves
- vessel chartering
- weather forecasting/hindcasting
- well testing

Preliminary endeavours were made by the authors to assess the nature of support industries prior to verification of the remits and activities of other state agencies. The findings of this limited data gathering exercise are presented in Table.2.2.
**Table 2.2 Results of survey of support businesses and service companies.**

<table>
<thead>
<tr>
<th>Company</th>
<th>Nature of business</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amergen International Oceanographic Services</td>
<td>Metocean data collection and processing</td>
</tr>
<tr>
<td>Aqua-Fact International Services Ltd.</td>
<td>Seabed sampling, EIS, biological and chemical monitoring, emergency response plans, oscillation, oil spill modelling, cutting and sediment plume modelling, hydrographic studies, seabird studies</td>
</tr>
<tr>
<td>Aquaphoto Picture Library</td>
<td>Marine photographic resources</td>
</tr>
<tr>
<td>Campbell Catering</td>
<td>Offshore catering</td>
</tr>
<tr>
<td>Chartnernav</td>
<td>GPS services</td>
</tr>
<tr>
<td>CSA</td>
<td>Economic, geological, geophysical, geotechnical, computing and training services</td>
</tr>
<tr>
<td>Dames &amp; Moore</td>
<td>Environmental management services, offshore E&amp;P environmental support, offshore seismics, drilling operations, offshore operations, decommissioning, risk and reputation management, environmental software tools</td>
</tr>
<tr>
<td>EDC (Europe) Ltd</td>
<td>Site investigations, drilling investigations, drilling rig logistics/offshore support</td>
</tr>
<tr>
<td>F. Barrett &amp; Co.</td>
<td>Mooring buoys, oil pollution booms, marine cranes</td>
</tr>
<tr>
<td>Fastnet Geophysical</td>
<td>Geophysical processing</td>
</tr>
<tr>
<td>Foynes Seabase Ltd</td>
<td>Offshore base management, warehousing, sea/road transport, airport logistics</td>
</tr>
<tr>
<td>Hydrographic surveys Ltd</td>
<td>Marine consultants, survey company, bathymetric surveys, site investigation, client representation, geophysical investigations, pipeline surveys</td>
</tr>
<tr>
<td>Irish Hydrodata Ltd.</td>
<td>Marine consultants, survey company, bathymetric surveys, site investigation, geophysical investigations, pipeline surveys, oceanographic modelling</td>
</tr>
<tr>
<td>Informatic Management Ltd.</td>
<td>Data management and software services. Oceanographic equipment agent.</td>
</tr>
<tr>
<td>Kilrush Marine Services</td>
<td>Offshore engineering, component supply, servicing to the offshore oil/gas industry</td>
</tr>
<tr>
<td>Met Eireann</td>
<td>Metocean forecasting</td>
</tr>
<tr>
<td>Metlab International Ltd.</td>
<td>Offshore engineering, Pipeline surveys, non-destructive testing</td>
</tr>
<tr>
<td>Project Management Ltd.</td>
<td>Environmental Impact Assessments, site &amp; geophysical investigations, drilling investigations, drilling rig logistics, offshore support, analysis of services in retrieval samples and drill material, offshore engineering, pipeline surveys</td>
</tr>
<tr>
<td>Schumberger Geco-Prakla</td>
<td>Seismic surveys</td>
</tr>
<tr>
<td>Sea &amp; Shore Safety Services Ltd.</td>
<td>Training, safety equipment supply, lifejacket servicing.</td>
</tr>
<tr>
<td>Wire ropes Ltd</td>
<td>Steel wire rope manufacturers, lifting gear specialists</td>
</tr>
</tbody>
</table>
Whilst Table 2.2 presents a summary of the activities of those companies that responded to a questionnaire circulated by the authors, it is recognised that the rate of response was not high, and therefore this list is not likely to be fully inclusive.

Further information in this area has been obtained from the Offshore Oil and Gas Register, which is a list of companies “with added value to Ireland who have advised Enterprise Ireland of their interest in providing services to the offshore industry.”

The following Table 2.2.1 has been extracted from the directory and gives a short-listing for each company. The latest issue of this list containing full contact details and a longer description of each company’s activities was released in January 2000. It is available from Emer Butler at the Ocean Services Department of Enterprise Ireland.

Table 2.2.1 List of companies in Offshore Oil and Gas register with services provided

<table>
<thead>
<tr>
<th>COMPANY NAME</th>
<th>SERVICE HEADING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aer Lingus</td>
<td>Air Travel</td>
</tr>
<tr>
<td>Aer Turas</td>
<td>Air Freight/Courier Services</td>
</tr>
<tr>
<td>AID Chemicals Ltd.</td>
<td>Chemicals</td>
</tr>
<tr>
<td>Allied Irish Bank</td>
<td>Banking Service</td>
</tr>
<tr>
<td>Anderco Lifting Ltd.</td>
<td>Lifting Equipment, Ropes</td>
</tr>
<tr>
<td>Angus Fire Limited</td>
<td>Tools/Fire Equipment/Training</td>
</tr>
<tr>
<td>Aqua-Fact International Services Ltd.</td>
<td>Marine Consultants/Client Representation</td>
</tr>
<tr>
<td>Argosea Services Ltd.</td>
<td>Air Freight/Courier Services. Labour Vessel Chartering</td>
</tr>
<tr>
<td>Atlantic Marine Supplies Ltd.</td>
<td>Clothing and Equipment – Protective</td>
</tr>
<tr>
<td>Ballinphellic Engineering Company</td>
<td>Lifting Equipment</td>
</tr>
<tr>
<td>Bank of Ireland</td>
<td>Banking Service</td>
</tr>
<tr>
<td>BHP Laboratories</td>
<td>Steel Fabrication/Engineering Services</td>
</tr>
<tr>
<td>BMD &amp; Company Ltd.</td>
<td>Steel Fabrication/Engineering Services</td>
</tr>
<tr>
<td>BOC Gases Ireland Ltd.</td>
<td>Gas</td>
</tr>
<tr>
<td>James Bruen &amp; Sons Ltd.</td>
<td>Insurance</td>
</tr>
<tr>
<td>BSS (Ireland) Ltd.</td>
<td>Steel Fabrication/Engineering Services</td>
</tr>
<tr>
<td>Calnan Containers</td>
<td>Containers/Skips/Tanks/Baskets/Compactors</td>
</tr>
<tr>
<td>Cameron</td>
<td>Steel Fabrication/Engineering Services</td>
</tr>
<tr>
<td>Campbell Management Services Ltd.</td>
<td>Catering</td>
</tr>
<tr>
<td>Carbon Chemicals Group Ltd.</td>
<td>Chemicals Pollution</td>
</tr>
<tr>
<td>James E Carroll Onshore Services Ltd.</td>
<td>Tools/Fire Equipment/Training</td>
</tr>
<tr>
<td>COMPANY NAME</td>
<td>SERVICE HEADING</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Casey Travel</td>
<td>Air Travel</td>
</tr>
<tr>
<td>Ceramics Research Unit</td>
<td>Laboratories</td>
</tr>
<tr>
<td>Chemicals and Plastics Ltd.</td>
<td>Chemicals</td>
</tr>
<tr>
<td>Comex Ireland Ltd.</td>
<td>Diving/ROV Contractors</td>
</tr>
<tr>
<td>Consult-Us Ltd.</td>
<td>Laboratories</td>
</tr>
<tr>
<td>Cork City Fire Brigade</td>
<td>Tools/Fire Equipment/Training</td>
</tr>
<tr>
<td>Cork Dockyard Ltd.</td>
<td>Steel Fabrication/Engineering Services</td>
</tr>
<tr>
<td>CSA Group</td>
<td>Geological Consultants</td>
</tr>
<tr>
<td>Demesne Electrical Sales Ltd.</td>
<td>Electric Goods</td>
</tr>
<tr>
<td>Doyle Offshore</td>
<td>Base Services Labour Steel fabrication/Engineering Services Vessel Chartering</td>
</tr>
<tr>
<td>Dunmast Ltd.</td>
<td>Communications/Navigation Equipment</td>
</tr>
<tr>
<td>Dyno-Rod</td>
<td>Steel Fabrication/Engineering Services</td>
</tr>
<tr>
<td>Eastern Electrical</td>
<td>Electric Goods</td>
</tr>
<tr>
<td>Energy Services International</td>
<td>Marine Consultants/Client Representation</td>
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A notable recent addition to the list of service providers is Marine Technical Development Services Ltd. (MTDS). This is a joint venture company with the Marine Institute that incorporates some pre-existing elements including research vessel support services. Based in Galway beside the Marine Institute Technical Support Base, it is anticipated that this venture will build on existing specialist design and fabrication expertise and facilities to adopt a nationally strategic position in the research and development of a range of innovative marine engineering products and services.
2.3 Scope of RTDI Opportunities Associated with the Offshore Oil and Gas Sector

2.3.1 Introduction

This section of the report focuses on the hydrocarbon sector and draws out themes that offer potential in terms of providing opportunities for future research activity. The material is structured to present it as coherently as possible. Various cross-linkages and interactions obviously exist between the various headings that have been employed, and it is acknowledged that other ways of presenting the information are possible.

In identifying and offering potential projects and project themes it was decided to adopt as broad an interpretation of possible of the Marine Institute remit. Having identified the main domains of responsibility for the other state bodies concerned in this sector, these respective remits have also been closely born in mind during the study in order to avoid overlap as far as possible. Nonetheless, it is likely that Enterprise Ireland and PAD may consider some of the projects and areas identified as being more closely aligned with the responsibilities of those organisations.

The existing project management and assessment functions that have been established under the current administrative regime for the Petroleum Infrastructure Program (PIP) divide between four technical committees, with responsibility under the following headings:

- Subsurface
- Environment
- Sea-bed
- Metocean

As far as can be ascertained there are no plans to change this set-up in the near future. It would thus seem likely that the vast bulk of any future research projects connected in any way with the offshore oil and gas sector will pass directly or indirectly through the hands of these technical committees, and thus be dealt with under these headings. A natural route for involvement of the MI in this field would be through alignment with these existing projects and lines of research. It would be reasonable to assume that a considerable number of new lines of research will emerge during even the preliminary stages of these projects, or that particular aspects could benefit from supplementary and additional funding to achieve modified or higher objectives. For example some of the unsuccessful submissions made to PAD under the PIP funding rounds may warrant financial or other supports, and could be reappraised by the MI, subject to modifications and/or additions where necessary.

The various elements of this section are presented in a logical and hierarchical format, which draws on the key operational features inherent in offshore hydrocarbon activity as portrayed in Section 1.1. The basic criteria employed to prioritise among and within topics have been derived from available policy statements drawn from Marine Institute publications within the context of the national development plan and foresight initiatives (Marine Institute, 1998; Forfas web-pages, 1999; National Development Plan, 2000). Research themes and priorities are also established in the light of existing programs of research particularly through current and past EU programs. The views of prominent analysts from within industry have also been taken into account, particularly where they point to specific key
areas that have solid, long-term market potential. Whilst efforts have been made to avoid allocating projects to topical areas that may subsequently be deemed to lie outside the remit of the Marine Institute, some overlaps are inevitable. This occurs because the prior involvement of both PAD and Enterprise Ireland in the field, and the established and practical arrangement whereby the allocation of research between these groups has been (and continues to be) accomplished on an ad-hoc basis rather than according to an established and published regime.

Under the adopted scheme the main topical areas are dealt with in increasing detail, those items that are considered to offer the greatest potential have been accorded the most attention. Projections have been made where sufficient information was available to do so and where the subject matter permitted. However, the rapid pace of change in many of the subject areas, enhanced by the ever-increasing speed and affordability of computing power makes detailed long term forecasting a highly speculative activity.

The following quotation accurately sums up many of the views encountered during the course of the current study:

"Whilst there are undoubtedly many areas where fundamental baseline data are conspicuously thin or entirely lacking, other geographical or sectoral areas have produced large volumes of primary data. There is in general a huge demand for better ways of assimilating these data and disseminating information derived from them. This demand is being driven by the needs of administrators and decision makers for information in a form specific to their requirements."

2.3.2 Existing and identified areas of research relevant to Oil and Gas RTDI

Complementary themes to be in receipt of public funding under the objectives of the National Development Plan by means of institutional (or public) research; in-company research, and technology transfer are as follows:

- Marine environment through supporting research, monitoring, assessment and managing to meet both existing needs and the increased pressure on the living and non-living resource which will accompany a growing marine economic sector.
- Marine technology sector through developing new and innovative engineering technologies and products, with particular emphasis on the integration of information and communications technology (IT) with marine resource development.

The following more specific research themes were identified from SWOT analysis of the Marine Technology sector undertaken by the Marine Institute (Marine Institute, 1998).

- Support technologies e.g. Galway technical support base.
- Instrumentation development: marine safety services, environmental sensors, seabed crawler/instrument carrier.
- Offshore oil exploration and exploitation: metocean studies, thermo-plastics in flexible risers, composite materials, anticorrosion coatings, verification of wave tank modelling, floating production systems technology.
- Remote sensing: metocean studies, pollutant dispersal monitoring.
- Information technologies e.g. in the context of Maris (G7 initiative) maritime industry R&D masterplan of the Marine industries forum.
Marine research RTDI strategy for Ireland

The following are the main headings as identified in the marine research RTDI strategy for Ireland. These have been updated to include additional information where relevant.

- **Optics:** plankton samplers and imagers; shadowed image particle profiling (sipper); holographic camera for recording marine organisms; multispectral systems in marine optics; underwater mass spectrometer for in-situ chemical analysis.
- **Rapid area assessment:** AUVs and mounted equipment; shallow water real-time environment profilers.
- **Marine monitoring strategy:** co-ordination of activities from overall program objectives down to individual bio and chemo-sensors.
- **Sensors:** continuous developments are required, to
  - Improve precision, resolution and reliability.
  - Reduce size, cycle times, costs, maintenance, power requirements
  - Increase depth ratings, flexibility (multifunction), power supplies
  - Modify and improve software interface control and logging systems.

- **Deriving value from data:**
  - Data assimilation
  - Data synthesis
  - Data networks
  - Information systems

- **Sensing the environment, platforms, communications and networking:**
  - Vehicles-AUVs, moving vessel profilers, robotic inspection of sediments,
  - Landers-benthic landers for biogeochemical and sediment transport research.
  - Acoustic-underwater communications, deepwater, deep towed and high resolution chirp
  - Other instruments- e.g. modular instrumentation systems (black box), correlation velocity meter, fibre optic compass with integral motion sensor for survey and underwater application.

2.3.3 Euromar: An international framework for RTDI

This Eureka "umbrella" is devoted to the promotion and support of projects that are aimed at the development of advanced marine technologies. It liaises with the EU marine technology program and GOOS (UN intergovernmental Oceanographic Commission's Global Ocean Observation System).

The technological scope of the organisation is as follows:

- Oceanographic instrumentation and sensors (stand-alone, ship-borne, air-borne, and land based), including all marine geophysical, chemical, and biological technologies and from this resulting developments, products and services including those applicable or transferable to inland waters.
- Oceanographic measurement, monitoring, modelling, warning, hazard prediction, and other marine information systems (including components for shipping, transportation and port operation systems (like VTS, and ice-routing)
- Oceanographic platforms, carriers and vehicles (AUVs towed, ROVs, manned and unmanned subsirmibles, components for research, survey and special purpose vessels), benthic laboratories, buoys and drifters, as well as their subsystems (e.g. power, navigation, positioning, communication, data acquisition, vision and handling systems) and tools (e.g. manipulators)
- Marine telecommunication, informatics and telematics
- Seismic, hydrographic, bathymetric, oceanographic, and geotechnical, hydro-biogeochemical and hydro-meteorological surveys, research cruises and measurements including remote sensing
- Oceanographic services, including consulting and forecasting, value adding and provision of user-tailored information
- Miscellaneous services affiliated to oceanography of marine RTD (like RTD project support and management, data and information management, long-term data archiving, data quality control, presentation and public relation services.

2.3.3.1 Euromar networks

Euromar has initiated networks to promote and follow up international marine technology projects. The innovative network approach allowing users, demanders and customers to meet on a co-operative and equal basis.

Two networks have already been established:
1. Operational ocean monitoring and forecast network
2. Marine non-living resources and offshore technology

A further three are planned:
3. Marine living resources and biotechnology
4. Port, shipping, navigation and hydrography
5. Marine and polar research

Initiatives under the Euromar program would appear to offer a useful model and an appropriate mechanism for the commercialisation of advanced marine technological project ideas. Ireland does not currently have a representative in the program, and it is felt that a good opportunity exists for the Marine Institute to fulfil such a role.

2.3.4 Exploration & Production Technologies and Engineering RTDI

2.3.4.1 Introduction

Offshore hydrocarbon exploration and production is heavily dependent on technological innovation. This is especially true for deep-water hydrocarbon reserves where new technologies have, and need to be, developed to overcome the enormity of technical difficulties presented by deep-water frontier environments. Furthermore, technological development is economically feasible in this sector due to the potential cost saving that can be accrued from these advances. Offshore work in deep-waters is notoriously expensive, perhaps as much as ten times more expensive than near-shore operations. The huge costs of

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1 Further information about Euromar can be accessed at: http://www.adi.pt/euromar/welcome.html
production can therefore only carry small RTDI budgets. Against this background of reliance on new technologies, the traditional conservatism of offshore operators cannot be ignored. This is often reflected in the way final choices are made in favour of an existing technology, system or regime or manufacturer, rather than risking an innovative solution that although offering the highest technical or fiscal merit, has no track record.

Although the hydrocarbon sector in Ireland is likely to import much of the technology it requires from existing companies already supporting the hydrocarbon sector internationally, there may still be scope for indigenous RTDI initiatives.

The new frontier licences will be exploited through riser technology as opposed to conventional rigs. This technology is new and there is likely to be significant scope for engineering RTDI e.g. planning of anchor patterns/dynamic positioning, designing of riser systems, designing valves and riser components.

There is potential for joint ventures and technology transfer with multinationals to avail of RTDI needs with respect to electronic equipment, sensors and monitors, and the applications for new and innovative materials. SCADA systems provide supervisory control and data acquisition support and are increasingly finding application in any arena where there is a requirement to manage multiple networks. These could include multiple computers, sensors and machines. Advances are also being made in moving from analogue to digital (frame-relay) systems that offer higher speed and greater capacity.

Within Ireland, some initiatives have started which may benefit from additional support. For example, John Barnett & Associates Ltd. intends to set up an Offshore Marine Geotechnical Centre with PIP funding. This will provide applied R&D e.g. innovative sampling techniques aimed at retaining sample integrity, design methodologies, offshore foundation systems, as well as providing geotechnical and commercial laboratory services.

The development of infrastructure elements such as a national network of tide gauges and archiving and prediction system for coastal and offshore tidal data, is seen as long overdue. These could be linked to a system of enhanced meteorological and other observatories. Although tidal height fluctuations are of less consequence per se in the outer shelf regions, there are important linkages between tidal data from offshore gauges and satellite altimetry in relation to regional scale hydrodynamic modelling initiatives.

The development of new and novel exploration equipment has been strongly supported by the requirements of the hydrocarbon sector. The application of AUVs (Autonomous Underwater Vehicles) is detailed in the next section. The development of other survey technologies and production technologies also offers some potential.

2.3.4.2 Unmanned Underwater Vehicles, ROVs and AUVs

Although by no means exclusively associated with the hydrocarbons sector, this topic and especially that of AUVs is described here in considerable detail, as it is believed to represent one of the more important and exciting opportunities to be presented in the context of this study. Whilst various international initiatives will undoubtedly afford considerable scope for niche Irish participation, there would appear to be sufficient incentive in terms of long term domestic and global end-use requirement to advocate the development of an Irish AUV. Specific additional advantage is foreseen in the inherent magnitude of such an undertaking which could provide a highly visible, vitalising, and structurally cohesive focus for existing
and emergent marine (and other relevant) technological expertise. In other words the concept could become a vehicle not just in the physical sense, as a nationally strategic research tool, but also in the wider sense as a flagship project that would fast-track development in the sector in accordance with national strategic foresight objectives in marine technology.

**Key features of AUVs and their potential**

Autonomous underwater vehicles or AUVs are at the frontier of a branch of underwater engineering which has seen rapid evolution spanning 25 years. During this time the Remotely Operated Vehicle (ROV) has become a ubiquitous and indispensable tool for many E&P related activities, also being found in some form in most areas of underwater operations and research. The genesis of the ROV can be regarded as a model against which to obtain some measure of the likely future impact of AUVs.

Whilst ROV core design peaked perhaps ten years ago, with recent innovation going towards external technical developments in computing, electronics and specialised tooling packages, AUV design and development is still at a relatively elementary level, offering enormous scope and potential for innovation.

Unlike ROVs, AUVs are completely free of umbilical cables and are designed to carry out pre-programmed tasks completely independent of surface communication. Although at an embryonic stage of development the basic concept is now proven and about 50 existing prototype vehicles have successfully completed many often-remarkable missions. Several of the main commercial operators are now ordering AUVs.

**Future technological developments**

Westwood (1999b) cites the following medium to long term targets that are driving design imperatives in AUV development:

- deep-water operations
- power delivery
- reduction of costs

A host of innovations are required to achieve these goals both for ROVs and AUVs. High among these will be ways of abandoning hydraulic power for more efficient electrical systems. Reductions in the numbers of individual components and electrical connections exposed to seawater will save weight and increase reliability.

AUVs are expected to see increased service in the following areas:

- Seabed surveys
- Oceanographic data gathering
- Pipeline touchdown monitoring
- Floating Production System support operations-Hybrid AUV/ROV
- Military applications
- Application specific or customised variants

These applications are likely to be served through at least three main evolutionary groups of AUVs:
1. Survey AUV with the following features:
   - Low cost deployment system e.g. air, beach or small vessel
   - Long mission duration
   - Precise navigation
   - Large data storage capacity
   - Underwater docking for recharge and data upload
   - Low maintenance requirement

2. Pipelay AUV
   This application stems from the current requirement for two vessels to be involved in the pipelay process, the second vessel acting as an ROV platform to monitor pipe touch-down on the seabed. Specialised tracked AUVs are currently being designed which to automate seabed-monitoring functions, thereby saving a vessel.

3. Hybrid AUV-ROV.
   This type of system is the furthest away in developmental terms, but would require the following features:
   - Designed specifically for deepwater work and inspection
   - Deployable from an FPSO (floating production system)
   - Operable and maintainable by normal oilfield personnel
   - Capable of locking on to undersea power and communications port

One of the most interesting innovatory challenges faced by designers of future underwater vehicles in general will be to simplify operating systems, in order to reduce or remove the need for specialist technical expertise in the offshore sector, where it is becoming increasingly hard to attract technicians. Harnessing the enormous wealth of advanced computer soft and hardware engineering skills available in Ireland could convey a real advantage in this area.

**Current and future markets for AUVs**

Although often derided at their inception by a conservative underwater establishment, work-class ROVs alone (not including simpler inspection-class units) now have an estimated 1999 market of $240 million, at an average unit price of $3 million (Westwood, 1999b). Driving this market are growing prospects in several key sectors, primarily offshore oil and gas, submarine cables and marine minerals. Of these the first is by the far the biggest, with enormous growth forecast for the sector world-wide with an estimated doubling of the number of sub-sea installations coming on-stream by 2003.

The European context is somewhat different however in that the potential lies not in very large, deep and highly productive offshore reserves, rather the exploitation of large numbers of small fields which will be accessed by sub-sea wells tied back to existing platforms. Hence platform decommissioning can be postponed, however, this will necessitate comprehensive programs of inspection and maintenance. The underwater cable market is itself primarily driven by increased demand in telecommunications for the Internet revolution. Cable route surveys and cable burial are key activities in this area, the former highly suited to AUV operations, the latter to highly specialised ROVs functioning as underwater tractors and bulldozers. AUVs have however seen service including a notable operation over 300km under ice laying optic fibre.
Specific advantages over surface operated vessels are obtainable using AUVs. These include improvements in quality of data (owing to deeper deployments) and enormous cost savings over traditional survey techniques especially in deepwater environments. Fugro Geoservices is anticipating a reduction of 50% in survey time. Some of the worlds leading players are currently in the acquisition phase or are entering into a range of supply agreements. These include the following:

- Fugro Geoservices has ordered a 5000m-rated survey unit from ISE.
- C&C technologies have ordered a Hugin 3000 from Kongsberg-Simrad.
- Racal has a memorandum of understanding with Bluefin Robotics Corporation for two survey units, with options on a six more.
- De Beers Marine Ltd, South Africa has ordered a Martin AUV from Maridan in Denmark, which is also supplying a unit for work with the National Museum of Denmark.

**Future markets**

The exorbitant cost of deep-water survey is a problem commonly cited by oil companies. These costs can typically be approaching an order of magnitude greater than a shallow shelf counterpart. Much of the reason for this lies in the requirement for very long cables necessary to tow sensors at appropriate depths, which consequently extends the time required for all associated activities such as deployment, vessel run-in and turning. These factors are exacerbated by the extremes of weather often experienced, particularly in the Atlantic frontier province. Poor resolution is also a problem for hull mounted sensors in deep water, as is accurate positioning of deep-towed equipment. AUVs obviously have much to offer in these situations, however, it is likely that even greater efficiencies are possible with multiple units being deployed from a single conventional survey vessel, or ultimately replacing surface vessels entirely in some applications.

Another large market area is that associated with floating production systems (FPS), which expected to become the preferred method of exploitation in deep and shallow waters. The basic architecture of these types of system often involves very extensive networks of underwater infrastructure, pipes, manifolds and risers, all of which require varying levels of undersea intervention. Factors including the distance between these elements and remote location opens up the prospect of AUVs being deployed from the actual FPS itself, through linkage with a form of underwater ROV mounted docking system.

AUVs already have a proven track record in oceanographic research, and this is exemplified by the service record returned by Autosub with well over 100 successful missions. This unit was developed by the Ocean Technology Division of Southampton Oceanography Centre. Autosub is in effect an active test-bed for many aspects of AUV research, and is currently being modified for increasingly deep operations, with much of the structure rated at 6000m.

Pre-programmed data gathering missions are becoming more routine with enormous potential to increase performance through the incorporation of artificial intelligence allowing active investigative response to changes in field variables. A very extensive range of uses are put to AUVs by various military operators, some of which originated with the military or their suppliers such as Hydroproducts, and British Aerospace. These applications include surveillance, mine neutralisation, search and recovery, and naval hydrography. It is anticipated that the concept of autonomy will be fully implemented in the next 5-10 years with a suite of purpose designed roving vehicles, capable of data upload and power recharge.
at remote (subsea) moorings. Further details of some specific developments in underwater robotics associated with this field are given in Appendix VII.
2.3.5 Environmental RTDI

Offshore oil and gas related deepwater research and development that is linked to the environment is currently administered through the existing two PIP programs as previously described in section 2.2.3.2.

The ways that projects are assigned for administration under the groupings or headings in the PIP system may not accord with a classic view of the environment or that of the Marine Institute, in that there is clearly an identifiable environmental component associated with the seabed and water column which is not specifically addressed.

This component will be presented under the following headings:

- Seabed, and near seabed processes and biotopes both biological and physical
- Water column processes, and biota
- Atmospheric, above water processes and biota

It is noted that although production may occur in deep-waters, hydrocarbons, particularly gas, need to make landfall via pipelines to reach available markets. As a consequence considerable areas of slope and continental shelf can be added to those areas of seabed which require specific attention, and both sediment and biological environmental dynamics are needed to fulfil this brief.

2.3.5.1 Seabed, and near seabed processes (above and below) and biotopes, including both biological and physical aspects

The hydrocarbon sector requires quantification of the seabed environment for exploration needs, geohazard risk assessment and to meet the requirements of EISs. Several studies have already been completed or begun in this thematic area e.g. ENAMII, PIP and individual site appraisals. The major new seabed mapping initiative being administered by the GSI will necessarily generate data of direct relevance to OOGE&P (offshore oil and gas exploration and production) operations, as well as generating a host of opportunities for ancillary research with multiple applications.

Many parts of the continental slope to the west of Ireland are unstable with ample evidence of slumping and mass-wasting features. These unstable areas need to be fully assessed in order to quantify engineering design constraints for riser systems and evaluate the risk of slope failure and consequent losses. Furthermore, engineers need to understand and cater for seabed processes and sediment mobility. This involves an understanding of sedimentation through the basins including along-slope and up/down slope processes. Linkages also exist between sediment movements and current dynamics. There are biological components to these sedimentary systems involving methogenic and other exotic bacteria that provide good opportunities for research. There is also a cross-linkage with the suite of potential gas-hydrate projects, that also have a strong microbiological component (see section 4.2 for details).

Strong linkages have been suggested between gas seepage and the genesis of deepwater coral and carbonate mounds (see section 4.3 for details). It is hoped that research already underway to examine some of these mounds in detail (ACES, ECOMOUND, and GEOMOUND) will provide further clues and new avenues of research. Another aspect of
carbonate mounds relates to their biological status and the potential need for conservation strategies.

Perhaps of more direct concern to the offshore industry are the properties of below seabed sediments. Difficulties in imaging and understanding the nature of sub-seabed sediments can often make the difference between a successful and an unsuccessful well. The modern upper sedimentary layers are often used as analogues for deeper, harder to study ancient systems allowing more a meaningful understanding of reservoir structure and evolution. (Responsibility for sub-seabed research, and particularly that relating to reservoir geology is quite clearly regarded by PAD senior staff as falling exclusively within domain of that organisation).

As well as environmental research topics related to geological explorations and risk assessments, considerable RTDI opportunities arise in association with environmental monitoring under statutory requirements and EIAs. These RTDI needs include studies into biotope distributions, environmental assessments and audits, as well as baseline studies. Some of these requirements may be fulfilled through projects ancillary to, and during geological surveys or advanced analysis of remotely sensed data e.g. 3D-laser scanned visualisation for biological characterisation.

The dumping of drill-cuttings contaminated with oil based drilling muds will shortly be prohibited under environmental legislation. Alternative methods for disposal of cuttings are required with current methods including re-injection (CRI), cuttings wash systems, ship-to-shore systems (onshore disposal is problematic due to difficulties handling skips, especially in bad weather) and ultrasonic cleaning systems. RTDI into better methods is important, as the rate of disposal of cuttings is the limiting factor in drill progression. The release of toxins from contaminated drilling muds and cuttings is the subject of multiple research programs in several EU states and internationally. Although these should be dealt with through standard EIA procedures, there may be opportunities to undertake detailed examinations of the properties of benthic sediments and associated communities in the vicinity of these and other platform discharges at sites with conditions specific to Irish waters.

Other baseline work has been carried out (Wheeler, 2000) on some deeper (2000-2500m) parts of the shelf-break to provide preliminary assessments of baseline condition chiefly for macrofauna living on or above the seabed. This work has been conducted using deep-towed video camera, which produces imagery from which qualitative assessments can be made. There is in general need to undertake further work of this kind and to develop other rapid assessment techniques ideally capable of providing quantitative analyses.
2.3.5.2 Water column processes and biota

Effects of sonar on marine mammals

The widespread use of seismics and side scan sonar as a means of acoustic prospecting has given rise to considerable scientific and public debate in regard to the possible effects of high-energy sound sources on the health and behaviour of marine mammals, particularly cetaceans. Several international research projects are attempting to quantify the effects of various intensities and frequencies of sonar equipment on the behaviour of whales and dolphins. Whilst some localised effects on behaviour are clearly recognised there is in general a need to concentrate further study in this area. The CRC is currently involved in a PIP funded program (RSG/PSG) that is applying a proven methodology in providing reliable estimates of cetacean (and seabird) numbers in the waters to the west of Ireland. To this and other baseline data could be added further sets of observations, and post-mortem work with stranded animals to assess possible correlation with periods of high seismic vessel activity.

Oil spills

Of great concern in relation to the marine environment are the consequences of oil spills. Experience in the North Sea and elsewhere has shown that oil production and some level of spillage are synonymous. However, the effects of long term chronic low level discharge of oil contaminated waste waters and the like have also been linked with biological effects, particularly on larval or juvenile stages of sensitive organisms. In the context of Ireland’s relatively pristine marine ecosystem, any changes that may be associated with offshore activities need to be monitored and fully understood. In reality with such low levels of production and a large unenclosed sea area, chronic problems are unlikely to be manifest in the short or medium term, except in the immediate vicinity of a production platform, sub-sea installation, or terminals. There is potential for the development of monitoring systems for detection of low-level contaminants and also lab and field studies to enhance understanding of long-term exposures.

Fisheries

The question of interactions between OOGE&P and fisheries has also received much international attention, however, more recent consensus indicates that on balance there is very little evidence of negative effects in the long-term. In the case of the Gulf of Mexico, the presence of a very substantial amount and variety of hydrocarbon related seabed hardware has significantly enhanced overall biological productivity in the region through colonisation of manmade habitat analogous to artificial reefs. Similar but localised phenomena are noted in the North Sea. In some specific areas of known spawning or feeding grounds, application of the precautionary principal may indicate the adoption of seasonal closure to seismic or other oil related activities. This type of recommendation has been adopted for example in the Faroes Islands (Olafsson, 1997) in order to minimise or mitigate the potential effects of the offshore industry on nationally important fisheries. Other recommendations to have emerged from this review are as follows:

- Fishery related problems are included in the planning phase as early as possible.
- An investigation is initiated to demonstrate whether additional regulations are necessary in connection with the selection of areas for the oil industry.
Before every licensing round, the Petroleum Administration shall submit areas, proposed to
be licensed, to the fisheries authorities and other relevant authorities to hear if and to what
extent the areas are biologically or fisheries sensitive.

- The fisheries authorities shall provide skilled personnel to safeguard the interests of the
  fishing industry in relation to the oil industry.
- Fisheries organisations shall take the necessary actions in order to prepare for the oil
  industry.
- A consultative committee shall be established consisting of fisheries organisations,
  fisheries authorities, licensees and the Petroleum Administration.
- Damages and compensation provisions suggested in part 7 of the Draft Bill on Hydrocarbon
  Activities shall be implemented.
- Future offshore installations shall be designed so that the authorities have a real choice
  concerning removal, abandoning, dumping or onshore dismantling when the installation
  is decommissioned.

It is recognised that although some or all of these recommendations are of relevance in an
Irish context, many are already covered under existing practice, nonetheless there may be
some issues that warrant further attention.

Obvious restrictions exist to fishing within the safety exclusion zone of any sub-sea
installations including pipelines. The key to minimisation of risk to fishing vessels and sub-
sea hardware lies in accurate mapping of installations and the ready availability of such
maps to fishermen in suitable electronic formats. A good example of this can be seen in the
UK, where the Seafish Industry Authority through Seafish Technology (Kingfisher) has
undertaken to establish and maintain a regularly updated information service about offshore
oil and gas installations and industry activities for the benefit of fishing skippers. This
information augments existing navigation charts covering the UKCS, and is available to
fishing skippers of any nationality who are legally entitled to fish in UK waters. Further
information on this and other topics of interest is available at the website of the UK Offshore
Operators Association¹.

Very few studies have been carried out on the effects of the Irish offshore sector on
indigenous fisheries, and although this may warrant attention in the future, it is not expected
to generate much interest at the present time. Satisfactory fisheries liaison measures
(organised through the IOAA) currently ensure that research and fishing vessels do not come
into contact. However, with the likelihood of an increasing number of sub-sea installations
and pipelines, as well as a considerable number of cables of various types, the need for an
analogous charting system in Ireland may not be far off. Kingfisher charts are known to exist
for some Irish waters but their currency and extent have not been ascertained.

2.3.5.3 Above water processes and biota

Outside of basic EIA requirements stipulated under environmental legislation regulating
emissions and administered by the EPA, few specific and detailed scientific studies have
examined the effects of OOGE&P on the integrated biological and physical attributes of
atmospheric systems. Those of most relevance in the current context relate mostly to venting
of toxic gases and aerosols, and the distribution of seabirds. Studies to obtain baseline
qualitative and quantitative analyses of seabird distributions are currently being undertaken
in conjunction with cetacean surveys under a PIP funded initiative by the CRC and JNCC.

The monitoring of discharge plumes of gaseous and other material is controlled under existing statutory requirements in relation to both operational safety and environmental toxicity. Under normal conditions the direct environmental effects of this type of discharge are confined to the immediate vicinity of the source and are unlikely to offer much RTDI potential. However, more subtle longer-term diffuse effects are linked to changes in atmospheric chemistry, and thus global warming, although these are manifest at the global scale and not readily attributable to specific sources. The effects of catastrophic events such as blowouts and explosions offshore the western seaboard may warrant further investigation, given the prevalence of onshore westerly winds. Ongoing work with advanced atmospheric models aimed at re-analysing past records with a view to obtaining a better understanding of regional atmospheric dynamics and their effects on wave climate, (Ignacio Lozano, CRC personal communication) may eventually help to accurately predict the fate of toxic clouds resulting from such occurrences.

2.3.6 Metocean studies

Engineering for offshore systems requires detailed knowledge of environmental boundary conditions. It is therefore necessary to fully understand current movements and dynamics as well as sea-state for above water structures. Some advances have been made in this respect through the deployment of weather buoys and collection of a year duration current data from throughout the water column at strategic locations along the shelf break. However, further work may well be required to satisfy demand, and this may include the need for additional sensors such as pressure transducers for tidal monitoring.

As well as fundamental data, significant RTDI opportunities exist in data evaluations and interpretations e.g. metocean predictions of storm-tracks, hind-cast model validation. RTDI potential exists for the use of near real-time data capture and integration with full function metocean buoys currently deployed off the west coast. These feed into applications to provide advanced high-resolution weather alert and working window optimisation for hydrocarbon-related weather critical operations and general survey operations.

Linked to metocean conditions is the need to model potential pollution dispersant pathways as part of environmental requirements associated with hydrocarbon operations. This involves observation techniques, modelling resuspensions, tracers and impact prediction. Spillage events have and will continue to occur, giving rise to considerable potential for improvements in current oil-spill trajectory modelling, and other software initiatives aimed at interpreting the results of such trajectory modelling and assisting with response options on a regional basis. Proprietary systems are available but in most cases depend on crude generalised data when being applied to situations in Irish waters, owing to scarcity of available high-resolution oceanographic and bathymetric data. As these data become more generally available the opportunities for tactically focused products will increase. Some new work is already ongoing in this area (Brendan Dollard, personal communication, Enterprise Ireland/ERIS project, CRC-Coastal sensitivity index, and RACER project). Advanced remote sensing techniques for detection and tracking are also under development in several centres.

2.3.7 Information management

The collection and collation of large and disparate datasets to meet hydrocarbon sector requirements necessitates the use of information management systems to best utilise the data. The use of intelligent systems to formulate solutions in situations where there are
multiple disparate data sources offers RTDI potential. The development of "data reservoirs" based on fuzzy logic rule based expert systems offer potential, as do the advantages accrued from the standardisation of data for smooth exchange between data managers, collectors and users. These types of systems aim to take account of the imprecision within databases, and to deal with qualitative data when used in conjunction with issue analysis.

Marine information systems incorporating sensors, modelling, decision support, databasing and mapping components fit into this category. Commonality of core components is an approach that can facilitate across the board mapping, visualisation and data management priorities. The development of Coastal and Ocean Zones Display and Information Systems (COZDIS) is required. These are dynamic digital coastal and oceanic information charts that combine 4D environmental data to create environmental scenarios adaptable to a wide range of uses providing value added information. Interactive 2D and 3D visualisation tools for data handling and processing e.g. multi-attribute hydrographic data would facilitate the hydrocarbon sector. Wider applications for enhanced seabed imagery from bathymetric data, 2D bathymetric systems (e.g. SAR), the use of GPS data buoys for geo-referencing mosaic charts and environmental data collection all have RTDI potential.

2.3.8 Logistics

As well as requiring data gathering or software developments to feed specific or ancillary requirements, the diversity and complexity of hydrocarbon sector operational activity generates a need for management and logistical initiatives. Irish companies and/or individuals already serve some of these areas, however, further potential exists under some or all of the following categories:

- **Survey design and implementation:**
  - hydrographic
  - acoustic classification
  - pipeline and ancillary

- **Policy studies:**
  - development of detailed EZ management strategy
  - integrated ocean management plans
  - legal issues
  - monitoring strategies

- **Technical sponsorship:**
  - joint academic/industrial initiatives
  - training programs

- **Drilling and associated topics management:**
  - feasibility
  - appraisal
  - rig selection
  - downtime assessment

- **Safety case preparation:**
  - software-control
  - metering
  - maintenance systems
- flow systems
- fire/gas warning and safety
- insurance assessment
2.4 Summary of RTDI opportunities associated with offshore oil and gas exploration and production

The main headings from sections 2.3.4-2.3.7 are presented in summary below. These are preceded with several bullets suggesting and outlining initiatives in which the MI could take direct action, and which may serve to catalyse the activities that follow:

2.4.1 Preliminary action plan

- Clarify and strengthen, where appropriate, the precise role of MI within the context the of roles of other state agencies with respect to OO&GE. This would include PAD, Enterprise Ireland, the IOAA and GSI in relation to the National Seabed Survey
- Detailed follow-up and analysis of RTDI potentials through focused in-depth long-term programs allowing full inventory and development of strategic planning initiatives
- Active participation in international networks leading to detailed policy formulation and aggressive pursuit of strategic goals in marine technological development
- Feasibility study to examine the potential for a national program for the development of an AUV. This should build upon ongoing initiatives at the University of Limerick
- Infrastructural elements such as tide-gauge and meteorological networks
- Liaison for technology transfer, and support for training and experience in offshore, and onshore support technical specialisms
- Identification of human resource and training needs, and promotion of opportunities with regard to currently acknowledged shortages in this area

2.4.2 E&P Technology and engineering

- Components and control systems for ROVs and AUVs, including innovative manipulators and tooling, power systems and cost reduction
- Development of SCADA and other innovatory systems for supervisory control and data acquisition across a range of applications
- Support and continued development of existing areas of expertise such as riser technology, design of offshore structures and geotechnical support services
- Materials research

2.4.3 Environmental RTDI

- Seabed and near seabed processes including geological assessments and geotechnical characteristics in relation to engineering constraints
- Biologically related components of seabed systems including micro and macrofauna. Importance of methanogenic bacterial systems. Carbonate mounds and gas hydrates
- Environmental impact of OOGE&P activities, EIAs, long-term monitoring programs, toxic discharges
- Cetaceans and seabirds monitoring, baseline mapping and allied research
- Examination of potential effects on fisheries
- Enhancements and developments to coastal sensitivity index initiatives, data capture and software development
2.4.4 Metocean RTDI

- Support and development and enhancement of existing JIP programs e.g. Shamrock
- Deployment of oceanographic instrumentation, multiple sensors
- Development of new and innovative instrumentation packages and enhancements to existing systems
- Derivatives and enhancements to existing hydrodynamic models for dispersion and operational prediction. Coastal sensitivity indices.

2.4.5 Logistics

- Survey design and implementation-hydrographic, acoustic, environmental
- Policy studies concerning development of strategic planning initiatives for EZ monitoring and management
- Logistical co-ordination and assessment of potential for further and enhanced technical co-operation and sponsorship between industry, academia and state bodies
- Drilling project logistical management
- Safety case preparation
3 Aggregates

3.1 Extent of Aggregate Resources

3.1.1 Introduction
Extensive sand and gravel resources are known to exist in Irish coastal waters, although a full understanding of the nature and distribution of these resources is far from complete. Detailed investigations are an essential prerequisite to quantitative resource assessment, and these currently exist for a few limited sites only.

The following chapter presents an overview of Irish nearshore aggregate resource potential. This assessment is a generalised summary that has been compiled from a diverse range of information and data from many different sources. Primary among these in terms of area coverage and detailed high quality geological interpretation is the work of the Geological Survey of Ireland and the British Geological Survey in association with the University of Aberystwyth. These organisations have worked on a co-operative basis through numerous regional reconnaissance and exploration cruises for the last two decades, which has culminated in the production of a series of five regional seabed sediment maps.

To this body of pioneering work can been added information derived from a diverse assortment of 30-40 smaller scale surveys. A small number of these were specifically conducted for purposes of sand and gravel resource assessment over very limited areas, the remainder having been carried out largely for biotope and other environmental mapping and sampling projects.

The appraisal presented in section 3.1 is based largely on information contained in a database and GIS system that was constructed by the CRC under a project entitled:


This database is comprehensive, and is believed to house the bulk of available public domain data and metadata of relevance to the topic in Ireland. Several of the most relevant datasets have been selected for presentation in this appraisal. These data appear in the form of figures in the text. The full contents of this database and GIS have been passed to the Marine Institute, and a mechanism for their wider dissemination is currently in preparation.

3.1.2 Regional geological context for aggregate resources

The bulk of sands and gravels (collectively referred to as aggregates) found in Irish waters are derived from Quaternary (mainly Pleistocene) glacial deposits, supplemented by material derived from the Holocene reworking of former deposits under rising sea levels, and from smaller volumes material from coastal erosion. Based on preliminary evaluations of existing (at the time) reconnaissance seismic data within the 20m contour, Geoghegan, Gardiner & Keary, (1989), suggest reserves of several million cubic metres of gravel and perhaps 100 times that of sand. This is thought to be a conservative figure since it excludes potentially extractable reserves lying in deeper water within the 50m isobath.
The greatest volumes of Quaternary aggregate materials are found over much of central and southern Irish Sea, and the south eastern and north western coasts. Smaller volumes of material are located in embayments along the western coast and further offshore, but are not well proven. The present configuration of geological units that make up these sediments is a result of reworking by currents and wave action during a glacial-interglacial-glacial-postglacial series of events (Whittington, 1977, McKenna 1984, Warren and Keary 1989, Pantin & Evans, 1984). At least 4 distinct sedimentary units are variously described by these and other authors (Devoy, 1983; Eyles & McCabe 1989). Although these units vary greatly in thickness, and some may be untraceable in places, their presence is noted from many locations throughout the Irish sea, and analogous deposits have been noted on other areas of the Irish coast such as Dingle Bay (Shaw et al., 1994). In a few places, these sediments reach 100m in total thickness, although more commonly thickness ranges between a few centimetres (over bedrock or other consolidated units) and up to 70m or more in banks off the east coast. Geological investigations have been most concentrated in the Irish Sea, and extensions of this work to cover most of the east coast have led to a general understanding of the origins and provenance of marine sediments throughout that region. A set of five comprehensive regional seabed sediment maps produced by the BGS, (including some data supplied by GSI) cover the Irish sea, north east Celtic sea and part of the north west approaches including the Donegal coast at a scale of 1:250,000. In other areas not covered by these maps, information is patchy and incomplete. Detailed interpretations based on integrated sampling and shallow seismic/acoustic reconnaissance remains to be completed or undertaken.

Whilst an overview of broad sediment types and common bedforms can be obtained from these and other medium scale sediment maps at the regional level, it should be noted that where the maps may denote an area as being composed of one particular sedimentary type, in reality this is very seldom found to be the case. The actual seabed encountered, and the underlying sedimentary units are mostly heterogeneous, showing strong variations in character even over relatively short distances. The main controlling factors that influence present (Holocene) seabed morphology are the underlying sediments, and the effects of tidal currents and wave action. In many cases, sediment surfaces are being either continually or intermittently reworked. This hydrodynamic forcing leads to complex interactions where sedimentary features both influence and are influenced by water movement giving rise to many classes of bedform including sand and gravel waves, ripples, dunes, sheets and banks. The series of major sandbanks that lie sub-parallel to the east coast are a spectacular example of this type of interdependence (BGS seabed sediment maps; Pantin & Evans, 1984).

For representational purposes the coast has been divided into six areas that are shown in the following map series as discussion Figures 3.1 to 3.6.

3.1. East coast from Dundalk to Wicklow.
3.2. East and south east coasts from Wicklow to Youghal.
3.3. South and south west coasts from Youghal to north County Clare.
3.4. West coast from north County Clare to north of Galway Bay.
3.5. West coast from Clew Bay to Blacksod Bay.
3.6. North west coast from Blacksod Bay to Malin Head.
This sheet partition does not follow any particular geological divisions but facilitates consideration of resource relevant details at a meaningful scale. It should also be noted that although potentially valuable marine aggregates are undoubtedly present in (locally) large quantities across wide areas of the continental shelf, this study has been restricted with those that are found landward of the 50m depth contour (see section 3.2.2.1 for rationale).

3.1.2.1 East coast from Drogheda to Wicklow (Figure 3.1)

A wide coastal platform extends up along much of the east coast and the 50m contour is encountered between 20-25 km offshore. A line seaward of Drogheda has been taken as a north eastern limit of aggregate materials, marking a practical transition zone from sands into progressively finer sediments and eventually muds, extending northward into UK territorial waters. Several gravel patches in outer Dundalk bay are noted. However, they are likely to contain a significant proportion of fine sediments (silt and mud content is an important determinant of aggregate quality). The area immediately to the east of Dublin, and extending southward is known to contain large reserves of sands and gravel. The BGS sediment information (Figure 3.1) indicates a progression from sand dominated sediments in the north part of the area that includes the Kish and Burford banks, towards increasingly coarse sediments moving towards the south. These gravel-dominated areas include the Codling and Bray banks.

Although a broad regional understanding of formative geological processes is reasonably well developed throughout this area, detailed studies suitable for resource evaluation are only available for the Kish and Burford banks, (Wheeler et al., 2000) and the Codling Bank (Irish Hydrodata, 1996). A large number of smaller mainly biological and environmental studies have been conducted in the vicinity of Dublin (see list in Appendix VIII). The upper sedimentary unit of the Kish and Burford banks; Unit A (Wheeler et al., 2000) is thought to correspond with unit IV as described by Whittington (1977). Consisting largely of sands, and some gravel but also including clay layers, this unit was found to range in thickness from zero around the Muggins Rocks to c.30m at the bank crests. An average thickness of c.15m was found over flatter intervening seabed areas. Investigations that included large scale sampling (750kg grab) and vibrocoring were carried out on a 5km by 3km site on the Codling Bank on behalf of the DOM NR by Irish Hydrodata for the purposes of evaluating suitable material, 250,000m$^3$ of which is required for use in a beach nourishment program. Results of this survey showed that seabed material was quite variable in grain size and thickness of the various grades encountered. Findings indicated that the surface gravel layer was mostly in the order of 1.0m thick and contained high percentages of sand (30%).

3.1.2.2 East and south-east coasts from Wicklow to Youghal (Figure 3.2)

Continuing south from Wicklow Head as far as Carnsore Point, almost the entire seabed from shoreline to 50m contour is composed of sands and gravels in varying proportions. The coastal platform becomes significantly narrower in a southerly direction pinching in to within a few kilometres of the shore off Carnsore Point. Of particular note are the conspicuous banks that form a semi-continuous offshore barrier along this entire stretch of coast. Currents are particularly strong in this area giving rise to extensive mobility of surface sediments particularly in the sandier zones, whilst hard pavements exist in other areas where fines have been winnowed out leaving gravel and cobble pavements as a resistant surface crust. Significant coastal erosion is a noted feature along the east coast, and is problematic particularly towards the south in the vicinity of Rosslare. In some cases it is suggested that sediment flux is strongly linked to shoreline coastal systems in a series of sub-regional
sedimentary cells (Ray Keary, GSI (retired) personal communication). Quantitative understanding of these complex sedimentary systems is in its infancy, although studies are soon to be implemented which will examine their origin, dynamics and stability in relation to past, present and future changes in sea level. It is noted that many of the offshore banks are increasingly being scrutinised as potential sites for wind farms, as well as being subject, along with intervening areas, to aggregate prospecting license applications (Terry McMahon, FRC, personal communication).

Further south, in the vicinity of Wexford Harbour, larger areas of fine sediment including muddy sands are noted, particularly close in-shore. Rounding Carnsore Point, considerable expanses of bare rock outcrop are encountered at the seabed surface, and elsewhere in this region sediment cover may be reduced to a thin lag perhaps a few centimetres thick overlying the bedrock or consolidated quaternary glacial sediment. Moving further west, the coastal platform again widens, however, the inshore area out to beyond the 30m contour is dominated by bedrock or compact Quaternary sediment at the surface. Thin cover or occasional isolated patches of sands and gravels are found over these harder substrates but only west of the Saltees in the wide expanse of Bagгинbun Bay are thicker deposits of sands and gravels encountered. Along with these are several gravel patches, and extensive sheet sands in and around the mouth of the Suir estuary. Figure 3.2 shows the general (BGS/GSI) distribution of sediments as well as additional data obtained from other sources including RoxAnn and sampling programs carried out as part of the FRC work into herring spawning grounds. Spawning beds are likely to exist at various locations throughout this zone, which has collectively been cited as a spawning area (Breslin, 1998). Available evidence indicates that bottom conditions are highly variable throughout this region with localised transitions between rocky, shelly, gravely and sandy substrates (GSI seabed samples: Geoman, 1984; FRC sample data, 1996-1997; Aquafact, 1997).

Several deposits of commercial grade aggregate material are known to exist in this area, one of which is currently the subject of a longstanding license application (Martin O’Hanlon, Bilberry Shipping, personal communication). Interest in this deposit is focused towards gravel grades. Site investigations, mostly to establish baseline biological and environmental parameters have been conducted, and trial dredging runs undertaken to prove material quality and investigate overspill plume formation (Aquafact, 1997). Other studies are currently underway by a consortium of Universities under the aegis of the GSI to investigate the detailed structure of sediments in this and at least six other south coast sites including Dungarvan, Youghal, Cork, Courtmacsherry, and Kinsale. The work is being carried out as an adjunct to the national seabed survey and involves detailed mapping with multibeam sonar supplemented with chirp sub-bottom profiles. One of the main objectives is to plot the locations of paleochannels that were formed during periods of glacially induced sea level lowstand. The main rationale behind this work is to gain a fuller understanding of paleochannel evolution and morphology, and in particular the phase of infill that occurred during the final Holocene marine transgression c.5000 yrs before present. Such understanding is likely to provide useful insights into coastal processes, and the progression of sedimentary events and processes associated with present day sea-level rise.

From an aggregate resource viewpoint paleochannels are regarded as a significant source of construction materials, which have long been exploited on land. The viability of paleochannels as aggregate sources is dependent on the extent of overburden (see section 3.2.2.1).
BGS seabed sediment map coverage extends westward only as far as between Youghal and Dungarvan. Assessments of resource potential for the remainder of the south coast, and entire west coast has been based on assembly of many smaller and often discontinuous datasets as listed in Appendix VIII.

Several large and promising sandbanks exist off the mouth of Youghal harbour, although detailed resource potential in this area remains to be assessed. These banks may also be linked with the shoreline sedimentary system although the pathways remain to be investigated.
Figure 3.1: Seabed sediment map showing distribution of sands and gravels, and positions of major banks off the east coast between Drogheda and Wicklow. (reproduced from BGS seabed sediment sheets Anglesey, Waterford and Cardigan Bay.)
Figure 3.2 Seabed sediment map showing distribution of sands and gravels off the south and east coasts between Wicklow and Youghal, (reproduced from BGS seabed sediment sheets, Nymph bank, Waterford and Cardigan Bay. Other data shown include: seabed samples and RoxAnn. See Appendix X for full listing of sources)

- Position of potential aggregate extraction area currently subject to temporary exploration license arrangements.

Legend:
- Bed samples
- Gravel
- Sandy Gravel
- Gravelly Sand
- Slightly Gravelly Sand
- Sand
- Muddy Sandy Gravel
- Gravelly Muddy Sand
- Gravelly Muddy Sand

Admiralty Bathymetry:
- 5 m contour
- 10 m contour
- 20 m contour
- 30 m contour
- 50 m contour

GSI-BGS Seabed sediments:
- Gravel
- Sandy Gravel
- Gravelly Sand
- Slightly Gravelly Sand
- Sand
- Muddy Sandy Gravel
- Gravelly Muddy Sand
- Gravelly Muddy Sand
Figure 3.3 Seabed sediment map showing distribution of sands and gravels off the south and southwest coasts between Youghal and North Co Clare. Sample data from various sources (map production: Sutton, 2000. [See Appendix X for listings of source data])
Figure 3.4 Seabed sediment map showing distribution of sands and gravels off the west coast in Galway Bay and vicinity. Sample data from various sources (map production: Sutton, 2000. See Appendix X for listings of source data).
Figure 3.5 Seabed sediment map showing distribution of sands and gravels off the west coast from Clew Bay to Blacksod Bay. Sample data from various sources (map production: Sutton, 2000. [See Appendix XI for listings of source data]).
Figure 3.6 Seabed sediment map showing distribution of sands and gravels off the north-west coast of Co Donegal and north Mayo. Seabed sediment data taken from BGS Malin sheet. Sample data from various sources including Dames and Moore (1996). (map production: Sutton, 2000. [See Appendix XI for listings of source data]).
3.1.2.3 Youghal to north Clare (Figure 3.3)

West of Youghal Bay and along the south coast, the coastal shelf begins to narrow. Rounding from Cape Clear to the northern limit of Figure 3.3 (Liscannor Bay, Lahinch), the 50m isobath runs very close offshore, leaving only the harbours and embayments as possible sources of material. Most of these embayments contain areas of sand and gravel, and some are fairly extensive as in Dingle and Tralee Bays, as well as the Shannon Estuary. Cork Harbour has been subject to a series of detailed engineering site investigations associated with port developments for at least 30 years. Comprehensive stratigraphies (Devoy et al., in prep; Scourse et al., 1994) have been compiled for many areas of the harbour, and one of the largest extractions of marine aggregates in Ireland was undertaken at Spit Bank during 1996-97. In the order of one million cubic metres of fine gravel has been removed from the Spit Bank (lower harbour) and used for backfill during construction of the Lee Tunnel. Considerable volumes of aggregate, mainly consisting of fine gravels and sands remain within Cork harbour, although these are often characterised by high silt content, and in many areas overburden is present. These factors probably render the bulk of these deposits economically sterile at the present time. (T. Sexton, Port of Cork Company, personal communication). Although data are sparse, the area in the vicinity of the harbour mouth and southward to the 50m contour contains many sand and fine gravel patches some of which may be viable as reserves. Borehole data point to a high probability of paleochannels, although their structure and volume remain to be quantified.

As previously stated, to the west of Cork Harbour the coastal shelf begins to pinch in towards the land. The bays of Kinsale, Courtmacsherry and Clonakilty all offer some potential though this remains to be accurately quantified. The major inlets of the south west coast have all been sampled to varying degrees and show evidence of sand and gravel patches, particularly in mid outer regions, since the inner recesses (and extreme outer regions) of the bays trend towards finer sediments and silt in less energetic environments. An in-depth geological survey of Quaternary geology in Dingle Bay (Shaw et al., 1994) details the sedimentary morphology of principal sedimentary acoustic units, and contains a fine account of the distribution of aggregates within the bay. Fairly extensive areas of well-sorted fine sandy gravels were found, although a wide range of bottom types exists, including coarse boulder gravels, and fine muddy sands. The upper layers of Holocene marine deposits are typically thin (1.0m -2.0m). These consist of an extensive sand sheet that thickens to around 4.0m towards the eastern shore. The underlying consolidated sediments are interpreted as non-marine, consisting of glacial diamict, stratified glacial outwash, or fluvial valley fill (paleochannel). Re-worked marine gravels at the surface are likely to be in the order of 2.0m thick as well. A particularly notable feature of the bay is the wide variety of active bedforms attesting to frequent mobilisation of sands and gravels. This type of highly undulating terrain has negative implications from an extractive viewpoint (see section 3.2.2.3).

Both Tralee Bay and the mouth of the Shannon Estuary have been sampled, and found to contain extensive areas of sand and gravel. However, detailed geophysical or core data are lacking. The south Clare coast is characterised by a very steeply descending shoreline topography, with negligible coastal plateau. Further north, sampling coverage is sparse although extensive beach sands are present particularly in Lahinch Bay.
3.1.2.4 Galway Bay and environs (Figure 3.4)

Extensive seabed sampling surveys have been conducted throughout Galway Bay, mostly during the course of benthic biological survey programs. The sediment distribution map (O’Connor et al., 1993) was generated for purposes of illustrating the major biotopes of the area. Reconnaissance geophysical coverage has been collected by the GSI, however, much of this remains to be formally interpreted. Extensive areas of sand are noted, also several gravel patches, particularly in the vicinity of the Aran Islands. Some of these patches are known to contain very high percentages of maërl (see section 4.6). Another elongated area of gravel extends for a considerable distance along the northern shore. Remaining areas of the bay are characterised by very fine or muddy sands.

3.1.2.5 Clew and Blacksod bays. (Figure 3.5)

There are some areas of sand and gravel along this stretch of coast. Dense sampling in the south part of Clew bay shows a typically heterogeneous distribution of bed types, including large areas of Mearl. Glacial deposits in the form of drumlin swarms characterise the inner part of Clew Bay. Linking cobble and boulder banks extend between many of the drumlins, and coarse aggregates are known to extend offshore from these. However, the extent of reworking and re-deposition of viable thicknesses of aggregate materials remains to be ascertained. Sampling and geophysical investigations in Blacksod Bay by the GSI for mineral sands show the upper sedimentary unit to be composed of medium to fine (mineral) sands several metres in thickness.

3.1.2.6 North Mayo and Donegal (Figure 3.6)

For much of the Mayo and South Donegal coasts the coastal shelf is rather narrow, and sediment cover thin or absent, with extensive areas of exposed or semi-exposed bedrock. (Dames and Moore, 1996). Some sandy areas are present in embayments but these have not been quantified. Donegal Bay may have more extensive and possibly thicker deposits. North of Aran Island, the coastal plateau begins to widen, and is covered by very extensive areas of gravels and coarse sands. BGS seabed sediment coverage exists east of Horn Head (8 degrees west), which indicates considerable areas of sandy gravel extending eastward to the limit of Irish territorial waters. Although data quality is acknowledged to be rather poor over the Irish sector of the map, the limited data available suggest that there may be considerable aggregate resource potential in some areas. It is also noted that much of this region is regarded as herring spawning ground (Breslin, 1998). Specific reference is made to large linear and non-linear sand patches as bedforms identified off the mouth of Lough Swilly and Sheephaven (Pendlebury, 1974).
3.2 Factors Affecting Recoverability of Aggregate Resources

The resource overview presented in the previous section would appear to indicate the existence of a very substantial and extensive resource base for marine aggregates in Irish coastal waters. The suggestion that enormous quantities of material are readily available for extraction must be qualified. A more realistic view of the usable resource will emerge from the material presented in the following sections. The main factors that affect recoverability of aggregates are discussed. It is likely that at least some of these factors are currently acting as a brake on the overall development of this sector. Licensing and EIS issues also discussed in this section as these issues have sometimes been cited by extraction proponents as the major limiting factors in developing a chosen site (Frederick Norman, Zirconsult; Martin O'Hanlon; Bilberry Shipping, personal communications). Further details of licensing and EIS issues from a resource management and environmental perspective are presented in subsequent sections.

3.2.1 Logistical factors

This section sets out the main logistical and factors affecting recoverability of aggregate resources. Some of these factors can also be viewed from an economic perspective in so far as their effects may be tactically offset, but at a cost which may render the resource uneconomic. In seeking extraction site locations, preliminary evaluations of potential are chiefly made on the basis of the first three factors presented below, which cover most of the physical logistically limiting issues that must be considered. However, an exploratory license is required before site works of any description (including non-intrusive geophysical prospecting) can begin. Having chosen a promising area, a developer would then become involved with full EIS and extractive licensing procedures.

3.2.1.1 Depth of water in which deposits occur

There is a practical limit for recovery of 40-50m for existing standard dredging equipment. In practice 40m is regarded as a deep resource, which would probably entail plant modification through extension of suction pipes. Technological developments have enabled some deeper dredging with very large vessels and pump capacity or other specialised equipment (cf. diamond recovery), but commonly available plant cannot reliably or economically lift material from depths greater than these.

3.2.1.2 Overburden materials

Overburden is the mining term used to describe any unwanted material that overlies a target deposit. A variable thickness of overburden is often encountered in coastal marine settings as a layer or layers of marine worked finer grained or muddy sediment, that have accumulated over coarser more commercial deposits of sands and gravels. Removal of overburden normally compromises the economic and environmental viability of most buried marine aggregate deposits.

3.2.1.3 Site metocean conditions

Safe and efficient dredging for aggregates can only be carried below a certain wave height threshold. The actual limiting height will vary according to vessel size and configuration, but production is likely to fall dramatically in waves over 2.0 m. Wind and swell waves in excess of these values are frequently experienced around Ireland, particularly on exposed
south-west, west, and north coasts. Between Cork and Malin Head an offshore wave-height of between 1.0m and 1.5m is exceeded for 75% of the time (annual mean). These statistics (Draper, 1991) indicate that very significant periods of downtime are likely to be encountered by vessels attempting to work the western seaboard. Specialised equipment can be fitted to enable dredging operations to continue under more extreme conditions, but in general it is likely that the less energetic wave climate on the east and south coasts wave will favour development of resources in these areas. An additional limiting factor linked to wave climate is the effect of wave action on the seabed. This is reflected in the frequency of occurrence, and magnitude of bedforms, such as sand and gravel waves that are generated by the action of grounding sea swells, particularly during storm and gale events. Highly undulating bottoms are not conducive to efficient extractive operations, and are usually avoided. It is noted that areas of substantial bed-form relief and mobility are not confined to high wave energy environments, and are frequently encountered off the south and particularly east coasts in association with high rates of current flow.

3.2.1.4 Licensing and EIS

Licensing and environmental impact issues have had a continued and marked influence on the recoverability of aggregate resources, particularly from the perspective of potential extractors. Unfortunately, there is at present no consistent or coherent national policy framework in place upon which to base a rational and transparent procedure for licensing of extraction, nor are the procedural guidelines available for the preparation of standardised EIA statements. The direct effects of this hiatus can be manifest in practical terms as very prolonged delays between an applicant's first declaration of interest in exploration, and the granting of a license for extraction. The cases of Bray Urban District Council and Bilberry Shipping serve to illustrate this point. In the former case extraction has proceeded after a period of approximately four years, whereas in the latter case the applicants await a final decision following a period of more than eight years of ongoing negotiations, site investigations, and an environmental impact study. Other applications have been processed with remarkable speed and efficiency, as in the case for a large-scale extraction in Cork Harbour. It is acknowledged that nationally strategic circumstances may have impacted on the status of the Cork project, nonetheless, whatever procedure was followed at the time has not served to establish a precedent of use in the longer term. Under these circumstances, the whole licensing issue is viewed by many parties on various sides of the debate as a serious problem that requires urgent attention. The current record of national achievement in this field has certainly not engendered confidence, and it is quite likely that the entry of other (possibly major) players has been delayed as a consequence of uncertain and inconsistent handling of the issue to date.

3.2.3.5 Conflicts of use

Potential conflicts over usage or designation of seabed areas are itemised and addressed as a matter of course through EIS/EIA procedures that have been implemented under existing (non-specific) legislation. However, the following key issues are highlighted, as they figure prominently in ongoing debate in this area, and are likely to have a strong impact in planning outcomes. Unfortunately, current debate is highly polarised between the position of potential developers and various statutory, official and unofficial conservation, fisheries, and environmental groups and lobbyists. Good quality information is scant in the public domain, and unfortunately distribution of misinformation has also been noted, an example of which is given in Appendix IX, in the form of an erroneous and misleading newspaper article.
Offshore wind-farms
Considerable interest has been expressed by a range of groups in the development of offshore wind-farms, including the following:

- Kish consortium- (ESB International, Soargas, and Powergen)-sites off counties Dublin and Wicklow
- Renewable energy systems (Larne)- sites off counties Wicklow, Wexford, Kerry and Cork.
- Harland and Wolff- areas off Wicklow
- Sure Wind Partnership- areas off Co Wicklow.

Most attention has been focused on the east coast banks, which offer many advantages in this regard. Licensing application procedures are currently under consideration for several sites, in accordance with specific guidelines and conditions contained in DOMNR consultation, and draft policy documents1. Should developments proceed, safety and engineering constraints will mean that areas of potential aggregate resource will be rendered unusable within designated exclusion zones around these installations and their connections with the shoreline.

Shipping, fishing vessels and charted features
Various charted features, such as shipping channels, and existing cable, pipeline and outfall routes all have to be avoided by aggregate dredging operations, as do areas designated as sites for the disposal of dredged material (spoil from harbour and channel capital and maintenance dredging) and sewage or other sludge.

Herring spawning grounds
Another conflict has developed regarding the distribution of fish spawning grounds and the location of spawning beds within them. This arises through the apparent preference of herring (and some other species) to spawn in areas where gravels comprise a major constituent of the surficial sediment. For example, the proposed extraction area off the south coast (see Figure 3.3) coincides with a herring spawning ground. However, to date there is no evidence that the site of proposed extraction is co-incident with an actual spawning bed. Spawning areas are thought to cover large parts of the south and west coasts.

Sites of special scientific interest and national heritage
Proximity with any of the following designated areas: SSSI’s, Marine Nature Reserves (MNRs), Marine Consultation Areas (MCAs), and Marine Special Protection Areas (SPA’s) will almost certainly curtail all extractive activity within a specified distance depending on localised conditions. In addition, developers are required to ensure that there are no remains of archaeological value present within or adjacent to a potential site. Given the density of wrecks in the vicinity of many east coast banks, this requirement is likely to entail significant cost and time overheads, and may impact considerably on the availability of extraction sites.

3.2.2 Economic factors

This group of limiting factors has been classed as economic in so far as they include some of the major financial considerations affecting viability of offshore aggregate recovery.

3.2.2.1 Landing and cargo handling costs

Aggregate materials are inherently bulky and require the use of heavy-duty shore facilities in order to ensure fast and efficient off-loading and swift vessel turnaround. The level of investment required to install appropriate facilities from scratch can be quite large, in the order of IR£ 1-2 million. Therefore a potential developer would have to be in control of assured supplies of material, over an agreed minimum period to justify the cost of such fixed assets. Moreover, a sustainable operation is likely to require the throughput from a fleet of at least two standard sized vessels (Iain Williams, Readymix plc., personal communication). Landing costs for aggregate are currently above an economically sustainable rate at Dublin Port (Frederick Norman; Zirconsult, personal communication).

3.2.2.2 Distance to market

As with all low value bulky cargo there is a maximum economic transport distance for marine aggregates. To some extent this distance will depend on the grade/s, and thus the value of material in a given deposit, but in general it is ideally limited to about one day’s steam or between 100-150 km; usually nearer the former. Beyond these distances, costs become prohibitive other than for some types of high value speciality materials.

3.2.2.3 Geological site investigations and EIA's

Geological reconnaissance surveys are usually required to locate prospective areas. Normally these are carried out by specialised contractors or in some recent cases in the UK, in partnership with national mapping authorities (BGS). This type of survey work is costly and involves a combination of surface, and sub-bottom acoustic profiling, as well as programs of heavy grab sediment sampling. Once promising sites have been identified, reserves are finally quantified by means of a program of vibrocore sampling. The degree to which operators are willing to embark on this type of prospecting will to some extent depend on their access to existing material reserves, but also on observable trends in departmental and other institutional attitudes to aggregate extraction per se. Comparisons can be made with the offshore oil and gas sector in this regard.

The detailed technical specifications and requirements for EIA’s will be discussed in a later section. The costs associated with meeting EIA requirements can be a very significant factor affecting the recoverability of a resource. Unfortunately in the absence of an established set procedures or guidelines that would enable potential operators to forecast expenditure, these costs remain an open-ended variable (Martin O’Hanlon, Bilberry Shipping, personal communication). The key imperative in relation to EIAs, is that the overall process is outlined in binding regulation that has sufficient inherent flexibility to allow some degree of case specific tailoring. From a developers perspective this would facilitate the most prudent allocation of financial resources in manageable stages, allowing a proponent to withdraw if necessary, prior to having made large financial commitments to the EIA process with little prospect of return should results up to that point indicate that unavoidable negative impacts are likely to be encountered.
3.2.2.4 Variability of deposit material

As described in section 3.1, seabed sediments tend to be highly variable spatially both in the horizontal and vertical sense. Viable aggregate deposits or “economic aggregate” contains material that falls within a specific range of grain sizes and has limitations on the allowable quantity of unwanted contaminants. The constituents of various grades are described under industrial standards (EN IS 933 and BS 882 and 812). Sediments that are normally mobile under the influence of currents are usually the least preferred owing to their tendency to exhibit strongly modal grain size distributions (Iain Williams, Readymix, personal communication). A viable extraction site is one that contains sufficient economic aggregate within a well-defined area of limited size (e.g. 1km x 500m). To some extent techniques such as on site combination (composing suitable hopper loads from a range of individually unsuitable grades encountered across a site), screening, washing and recombining can compensate for deficiencies. However all of these activities add to costs, and, in the case of onboard washing or removal of fines, can give rise to significant environmental impact in the form of overspill plumes. Other important determinants of aggregate quality include:

a) the shell or carbonate content, which ideally should not exceed 5%.

b) the presence of common contaminants coal fragments, clay clasts, and pyrite crystals.

c) chloride (salt) content which is common to all marine aggregates.

d) heterogenous grainsize distribution (lack of a strong modality).

Even on the basis of this short summary of quality factors it can be seen that economic recovery of marine aggregates is highly dependant on accurately pinpointing relatively small production sites amid often large expanses of unsuitable substrate.

3.2.2.5 Market factors and demand

Aggregates, including those from marine sources, are regarded as an essentially non-renewable resource. The bulk of marine aggregates (particularly for construction purposes) are preferentially won from geologically relict deposits. Supplies of aggregates from traditional land-based sources are increasingly coming under pressure as demand for material is at an all time high under the influence of an unprecedented boom in the construction industry. It has been estimated that the demand for aggregates in Ireland has grown by over 300% over the last nine years (Clarinbold, 1998). Although detailed official estimates for aggregate demand and production are not widely available, Shells (1998) cites a figure of 50 million tonnes per annum. However, figures cited by the Department of the Marine and Natural Resources (DOMNR)¹ indicate a quantity of 102 million tonnes used by the concrete industry in 1999. In financial terms it has been estimated that construction output as a percentage of GNP has risen from 13% in 1994 to 19% in 1999 (Dept. of the Environment and DKM, 2000). These figures reflect a dramatic increase in aggregate demand that is linked to Ireland's burgeoning economy, and associated demographic factors, which together have boosted the requirement for housing, as well as educational and commercial property. Also to be considered are the very significant volumes of aggregates that will be required to implement current and future public large infrastructure projects, which are being funded under the national development plan. A cumulative increase of 25.5% in the growth of construction volume is anticipated by 2006 over a base year of 1999 (KPMG, 2000). There are other primary uses for aggregate that have not been quantified in

the Irish context but which may well exert further pressure on the supply/demand situation so far outlined. These include requirements for beach nourishment, and other applications relating to coastal defence or large-scale coastal engineering projects. Coastal erosion is expected to increase in many areas, in response to changes in weather patterns bringing increases in levels of storminess. Also associated with global warming is the projected rise in sea-level which is likely to pose a direct threat to low lying coastal areas, and mediate the shoreward delivery of increased wave energy, further compounding coastal erosion problems.

Although in general, demand is likely to be focused on the main population centres and corridors between them, there are regional biases in the demand for certain aggregate grades which are in turn dependant on the availability within the economic transport distance of suitable terrestrial supplies. Official statistics for current or projected aggregate material requirements broken down on a regional basis were not available at the time of writing. The following information has been obtained from an (unnamed) industrial source.

“Demand for heavier grades (gravels) appears to be adequately supplied from conventional crushed rock, or fluvial and fluvio-glacial deposits available in existing quarries. Sand grades are less widely available, the shortfall in supplies being most acute on the south coast.”

In this way, it can be seen that the economic viability of a given marine deposit may depend on it’s siting in relation to localised or regional shortfalls in available terrestrial (or importable) supplies.

3.2.2.6 Royalties

As yet, the issue of royalties has received little attention for marine aggregates, but the imposition of state royalties would obviously impact on the viability of extraction if set at too high a level.

3.3 Environmental Issues Associated with Aggregate Resources

3.3.1 Introduction to environmental effects of aggregate extraction

This section of the report presents a detailed summary of all the main environmental issues (physical and biological) that are associated with marine aggregate extraction. In EU states environmental issues have always been a determining factor in planning applications (Glynn, 1996). A combination of factors has led to a further sharpening of focus on aggregate related environmental issues. High aggregate demand (stemming from material requirements for sustaining infrastructural development internationally) is exerting increasing pressure to seek alternatives to diminishing terrestrial aggregate supplies. There is also a general surge of interest in EEZ resources of all types, and a convergence is increasingly recognised between the objectives of national geological mapping programmes and biotope/habitat discrimination, particularly within the last 3-6 years. This in turn has led to an increase in the volume of results that have become available from relevant research in the form of commissioned reports and mainstream scientific literature. Whilst there remain many aspects of this topic that require further investigation, some of the more significant environmental effects have been quantified. Many of the issues that arise in association with aggregate extraction are linked to complex, interacting physical and biological processes.
over a broad range of spatial and temporal scales. Current consensus indicates that the negative effects of carefully managed extraction can be restricted to relatively small areas immediately in the vicinity of a given extraction site (ICES WGEXT\textsuperscript{1}, 1997, 1999, & 2000). The principal exceptions to this being the effects of sediment plumes, which can extend over wider areas depending on ambient conditions and other factors (see section 3.3.2.5). It is noted that there has been a shift of research emphasis away from the primary biological and physical impacts of dredging at the point of extraction and studies on recolonisation. Attention is now being focused on developing more detailed understanding of: a) secondary effects \textit{i.e.} dispersion of dredge plume sediments, resuspension of fines and their transport out of the dredge area (ICES WGEXT, 1999), and b) strategic cumulative effects (Oakwood Environmental, 1999).

3.3.2 Impacts of dredging on the Environment

Most marine aggregates are nowadays recovered by the use of self-contained seagoing dredgers that employ a centrifugal pump to lift material from the seabed into a hopper. Often the aggregate is then screened before being transferred to the hold. Screening requirements depend on the mix available in native deposits, and the preferred end use. Adjustment of the sand to gravel ratio is often carried out on board, where possible through selective dredging to derive ratios between 50:50 and 65:35 depending on customer requirements. The impacts of dredging presented in this section have been compiled from numerous (mostly international) sources, and are set out according to an EIA format. It is stressed that the relative importance of individual and combined impacts can vary considerably at different sites depending on localised conditions. The National EPA guidelines for environmental impact assessments (1995) recommend consideration of impacts under all of the following headings.

- human activities
- flora
- fauna
- soils and geology
- water
- air
- climate
- land topography
- material assets
- cultural heritage.

3.3.2.1 Impacts on human activities

- Potential for direct and indirect employment through at-sea dredging crews, operational/administrative staff, and shore-side cargo handling
- Conflicts with fisheries e.g. shrimp fishing gear and operations, herring fishing, sports diving. Loss of trawling gear has been cited in relation to large scale alteration of seabed topography (Oakwood Environmental, 1999)
- Potential long term or cumulative effects on fishery derived incomes have been identified (Oakwood Environmental, 1999). These authors point to complications in

\textsuperscript{1} International Council for the Exploration of the Sea-Marine Habitat Committee-Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem. The annual reports of this group represent the most important international source of information in the field.
quantifying these aspects in view of the notorious discrepancies inherent in catch statistics and valuation of impacted inshore fisheries

- Conflict with dredge-spoil dumping areas has been cited in Irish waters (Aquafact International Services Ltd., 1997)
- Cable-routes, pipelines, military restricted areas
- Sea traffic; other users of channels and seaways, sports divers, yachts and other leisure craft

3.3.2.2 Impacts on flora

The impacts on flora and factors influencing the extent of this impact include the following:

- The ambient turbidity ranges of an area (prior to any dredging)
- Abundance and diversity of existing species in an area (algae and seagrasses)
- Strength of local adjective processes in relation to capacity to export plume derived material (see below for plume effect details)
- Reduced light penetration can effect macrophytes (see for example ICES 1997 report on the Baltic)
- Increased turbidity may also depress phytoplankton productivity due to a reduction in light penetration into the water column. This effect is localised and is unlikely to be significant in terms of total production.

3.3.2.3 Impacts on fauna

Dredging has multilateral effects on fauna, i.e. those caused directly by the action of the draghead and pump; secondary impacts caused by dispersion of fine material from plumes; and subsequent effects on predator species that can be impacted through reduction in food species at lower trophic levels. In addition, certain areas of the coast and adjoining marine territory have been proposed and designated as SACs (Special Areas of Conservation), NHAs (Natural Heritage Areas), and SPAs (Special Protected Areas). All of these areas contain species or habitat that are protected by relevant national and EU environmental legislation in each case. The proximity to such areas of any proposed extraction sites would obviously require detailed considerations of all potential impacts.

Primary effects

- Almost complete destruction of all organisms that lie in the path of the suction drag head, with the exception of a few fast moving species that may be able to avoid it, and some species that can survive the process (ICES WGEXT, 1999)
- Significant changes in substrate composition can mean that communities developed through post extractive recolonisation can be markedly different (increases and decreases) in terms of biomass and diversity from pre extractive communities (Kenny, et al, 1998).
- Significant changes in physical topography of the seabed e.g. creation of deep pits or furrows, can alter the ambient hydrodynamic balance of the local ecosystem, in extreme cases leading to the development of hypoxic or otherwise adverse conditions. Increased sediment deposition and the modification of sediment type are potentially the most significant effects on marine ecology after the direct removal of the substratum and associated communities by the drag pipe.
Secondary effects

- In sheltered areas, sedimentation is mainly confined to a zone of a few hundred metres from the point of discharge (i.e. Newell, Hitchcock & Seedier, 1998).
- In high energy environments impacts of deposition can extend far from the dredging area (>1km). Should significant deposition of sand occur in areas that have a similar sediment type, the impacts on the benthic communities are likely to be small or can actually result in an enhanced biomass or diversity.
- The effects of elevated turbidity and sedimentation are more significant in environments that have naturally low concentrations of fine sediments, particularly in areas dominated by gravel substrata.
- Fish are potentially sensitive to sediment in the water column and material settled on the seabed.
- Dredging plumes may affect fish larvae and eggs that concentrate in the surface layers. However, there has been little work on the subject.
- Fish spawning is affected where the settlement of sediment directly smothers fish eggs or changes the composition of the substratum of a nursery area.
- An increase in the fines content may prevent the eggs of species such as herring and sand eel from adhering to the sediment, and can cause smothering of the eggs.
- Demersal spawning species that require a particular sediment type on which to spawn are possibly most susceptible to changes in sediment composition.
- Possible direct effects include abrasion resulting in the removal of mucus and the clogging of gills. However, it is uncertain whether these effects are likely to occur to a significant extent in practice, as fish are likely to avoid areas with sufficiently high turbidity.
- Plumes may change the behaviour of fish that target their prey visually. Fish that normally inhabit relatively clear water may have their feeding pattern impaired.
- The potential for impacts on fish migration depends on the duration and timing of dredging.
- Migration is seasonal so the impact would be more significant if the dredging occurred during the critical period.
- Settlement of the sediment can affect epifaunal crustaceans, and a localised redistribution of crustaceans can occur as a reaction to habitat loss.
- Silting up of lobster, and shrimp pots can lead to declining catches from traditional fishing grounds.
- The limited near-field dispersion and short-term duration of significant sediment plumes would only result in localised direct impacts on shellfish. However, such effects can impact on commercial shellfisheries.
- A few recent assessments in the Baltic have examined the extent of effects on seabirds mainly as a tertiary consequence of plume effects on water quality and benthic organisms described above. These effects may include: reduction of feeding conditions for divers, reduction of food resources for benthivorous, herbivorous and piscivorous species.
- In Ireland concerns have been raised in relation to the sand-eel populations of east coast banks. Sand eels (Ammodytedae) have been recognised as an important component of the diets of seabirds (Wagner, 1997; Halley et al. 1995) and seals (CRC, 1997).

3.3.2.4 Impacts on soils and geology (seabed sediments)

- Short medium and long term (semi-permanent) alteration of substrate grainsize distribution or composition can result from dredging depending on the conformation of local sedimentary sequences and the depth of penetration (Hitchcock et al., 1999).
- Rates of recovery to pre-dredge bed profiles through infilling of borrow pits or dredge furrows vary considerably from months to years depending on local hydrodynamic conditions and the depth of extraction.
- Significant alterations in bed level and/or conformation of sedimentary features such as sandbanks and bars may lead to permanent impacts both locally and at locations remote from the dredge site if they happen to be linked through sediment transport pathways.
- The significance of effects on regional scale waterborne sedimentary dynamics is often hard to gauge, requiring the use of hydrodynamic modelling in order to attempt predictions. In general, serious increases in shoreline erosion have historically been associated with near-shore extractions from within the 20m contour (Brady, Shipman and Martin, 1997).
- Alteration or removal of shallow barrier features such as large offshore banks can increase the quantity of wave energy reaching otherwise protected shores, potentially leading to increased rates of coastal erosion.
- The replacement of part of the current and future national aggregate requirement from marine aggregate deposits, would help mitigate environmentally deleterious effects to landscape and geological formations at terrestrial extraction sites, (as well as alleviate congestion, noise and air pollution along haulage routes).
- Many areas of uncertainty remain, including the extent to which removal of large quantities of marine aggregates from multiple licence areas might have effects on wave height, wave refraction, beach drawdown into the excavated area and other coastal processes which are of importance in beach replenishment and coastal erosion.

3.3.2.5 Impacts on water and discussion of plume effects

The impacts described above clearly illustrate that dispersal of fine material in plumes can be environmentally significant. A recent report commissioned by CIRIA\(^1\) (John \textit{et al.}, 1999) was undertaken by Posford Duvivier Environment together with HR Wallingford and the Centre for Environment Fisheries and Aquaculture Science (CEFAS). This was a desk-based review of the current state of knowledge on the nature of sediment plumes arising during dredging operations and their effects on the environment\(^2\). The work was funded by a number of organisations (including the UK and Netherlands Governments, and sectors of the dredging industry) reflecting a wide platform of interest. The project focused mainly on the UK situation, but several case studies and research from other countries was included. This study considered both the generation and subsequent mobility of plumes and the associated environmental effects, and undertook provisional studies to develop a structured framework for assessing the environmental effects arising from dredging activities. The resulting analyses could be used as part of the EIA process to determine whether plumes are likely to have unacceptable effects on the environment. Consideration was also given to mitigating measures to reduce potential impacts. The study looked at both aggregate dredging and capital and maintenance dredging, but not the effects of plumes from disposal operations or secondary re-suspension although it is recognised that this might be significant. The report identified a number of effects that plumes could potentially have on the marine environment, some of which were considered to constitute major effects, while others were potentially of minor significance (being more relevant to capital and maintenance dredging). These

1 CIRIA, The Construction Industry Research and Information Association is a UK-based research association concerned with improving the performance of all involved with construction and the environment (see: http://www.ciria.org.uk).

2 This work is available for sale directly from the CIRIA website.
impacts have been described above under individual impact headings (flora, fauna etc.). A
further study (Hitchcock et al., 1999) commissioned by the US Department of the Interior
examined plume formation and dispersion processes in thorough detail. This work was based
on in-depth analyses of a large body of field observational data collected during the course
of actual dredging operations. This report is recommended as seminal source of information
on the topic and is likely be used by a range of national authorities in drawing guidelines on
dredge related EIAs, and in the review of dredge plant performance. A number of points
arising from these reports are presented below:

Sources of sediment plumes
Marine mining vessels working in the UK have been shown to return as overspill and
unwanted screened material, between 0.2 and 5 times the cargo load (Hitchcock et al.,
1999). Surface plumes arise from overspill and discharge, and benthic plumes are
produced as a consequence of draghead friction over the seabed. Overboard material
contributions to total suspended load are 4-5 orders of magnitude greater than from the
draghead, thus the latter can be considered as negligible. Two ‘phases’ have been described -
the dynamic phase (where the plume moves under its own volition) and the passive phase
(where the plume moves due to other influences acting upon it), although it is possible to
have both phases present at the same time. In the dynamic phase, plume behaviour is
determined mainly by the nature and concentration of the material and the means by which it
is placed in the water. In the passive phase, plume movement is controlled to a greater extent
by the hydrodynamic environment (mainly the strength and direction of the current). The
primary factors that determine the nature of the plume are the dredging technique, the
sediment type, the hydrodynamic conditions and their interaction. In general it has been
found that material is deposited much faster than would be assumed from conventional
Gaussian diffusion models, and that sedimentation is largely confined to distances of a few
hundred metres from the point of discharge. Quantities of organic material are released into
the water column, most of which arises from maceration of benthic organisms. It is thought
that this material may play an important role in the enhancement of secondary production in
areas immediately surrounding a dredge area (Hitchcock et al., 1999).

Cumulative effects
- In the context of sediment plumes, a cumulative impact is considered to constitute more
than one dredging event creating multiple plumes.
- In isolation, one dredging regime may not have a significant impact. However, the
cumulative effect of several dredging regimes might exceed a critical threshold.

3.3.2.6 Impacts on air
Very little data are available that relate to impacts on air quality. Studies have been carried
out in Denmark (ICES WGEXT, 1999) in which the energy consumption and emissions
from extraction and transport of marine and land based resources have been being explored.
This work was published in Danish, however information communicated by the author
indicates that energy usage between 25% and 50% greater for sea transport of dredged
material than for road haulage. Values for land transport range from 50 MJ/m$^3$ (thousand
joules per cubic metre) at 50km to 300 MJ/m$^3$ at 300km, and sea transport values range from
125 MJ/m$^3$ to 325 MJ/m$^3$ for equivalent distances. Despite the higher figures for energy
requirement of sea transport, the effects of resulting emissions at sea are probably
insignificant given the potential for dispersion. On the other, hand the cumulative effects of
lorry exhaust frequently give rise for concern particularly in confined urban environments.
3.3.2.7 Impacts on climate
The total volume of emissions from dredgers is considered to be negligible in terms of contributing greenhouses gases linked to global warming and climate change.

3.3.2.8 Impacts on land topography
The potential impacts listed under this heading are linked to those listed under heading 3.3.2.4 soils and geology (seabed sediments). Here however, emphasis is placed on the potential for aggregate extraction to cause secondary effects on land or at the shoreline.

- The most significant effects of this type are more likely to be encountered as a consequence of long term, intensive dredging activity. Removal of large quantities of marine aggregates from multiple licence areas might have cumulative deleterious effects through impacts on wave height, wave refraction, beach drawdown into the excavated area and other coastal processes that are of importance in beach replenishment and coastal erosion.
- The replacement of part of the current and future national aggregate requirement from marine aggregate deposits, would help mitigate environmentally deleterious effects to landscape and geological formations at terrestrial extraction sites (as well as alleviate congestion, noise and air pollution along haulage routes).

3.3.2.9 Impacts on material assets
This heading encompasses a broad range of possibilities, some of which (e.g. effects on fishing gear and equipment have already been covered under previous headings.

- Potential effects may be more tenuously linked with extractive activities and could include loss of property or buildings owing to increases in coastal erosion.
- All sub sea installations including cables, pipelines, military closed areas obviously have to be avoided, and this is usually addressed through inclusion of buffer zones or exclusions in incorporated into the terms of licensing.
- Gross alteration to sub sea topography resulting in hummocks, furrows or ridges can cause direct damage to benthic trawling gear. This is most marked where static dredging is undertaken with clamshell buckets, or where deep borrow pits are excavated.
- Although data are lacking, it is possible that the operational interests of existing aggregate suppliers may be adversely affected through entry to the market of additional suppliers providing aggregates from marine sources.

3.3.2.10 Impacts on cultural heritage
Marine Archaeology
The potential destruction of known and as yet undiscovered artefacts and sites of archaeological value is a very real and topical concern in Ireland as elsewhere, and all activities within the 12 mile limit are bound by legal statute in respect of national maritime heritage. Strict guidelines are in place requiring developers to ensure that any areas subject to disturbance are fully surveyed to highlight artefacts of archaeological value prior to commencement of work. Regulations requiring the provision of detailed archaeological surveys for all areas of the seabed likely to be impacted by any form of potentially destructive activity (including dredge spoil dumping), have been more rigorously applied in
recent times. Under these regulations high resolution survey records (usually side scan sonar) are submitted to the Marine Archaeological Section of Duchas, for assessment. Further (manual) investigation of potential targets may then be required.

Particular concerns have been raised in respect of offshore aggregates since these are often extracted from submerged paleochannel systems. In the UK, similar onshore ancient river systems have yielded significant quantities of archaeological material, associated with patterns of Palaeolithic human settlement that typically favoured similar river terrace settings. Although no conclusive Palaeolithic finds have been reported from Irish coastal waters the possibility of these and other artefacts existing in offshore sand and gravel deposits cannot be ruled out (Breen, 2000). Archaeological potential is not spatially constant within potentially extractive areas, and knowledge of depositional age, and the extent of post inundation re-distribution of sediments is required to make informed judgements in this regard. The fate of artefacts subsequent to their entering the dredgers draghead, pump and screening systems is open to conjecture though object size may be important. Although it is possible that previously unknown artefacts may be detected through the dredging process (Aquafact, 1997). It is questionable whether in practice, any artefacts surviving the destructive forces encountered during transit from the seabed, would: a) be recognisable to a non-expert; b) be noticed in sufficient time to record anything but a very generalised discovery location.

The presence of shipwrecks is the other main aspect of cultural heritage of relevance to be discussed here. Records of vessels lost in Irish waters number in the thousands, c.2000 of which have known co-ordinates, the remainder being located by description. Shipwreck distribution is very uneven; unsurprisingly the highest density of shipwreck occurrence is inshore and co-incidental with the shallow banks (of known extractive potential) off the eastern seaboard. The bulk of recorded wrecks originate from Post-medieval and Modern periods. However the potential for wrecks within a given area will date from the time of inundation, possibly as far back as Early Mesolithic period. The survival of wrecks of stone age boats has been speculated for UK and Irish waters. All Bronze Age boats discovered to date in UK waters have been close inshore, and it is likely that remains of any undiscovered wrecks, possibly dating back to the Iron Age, may survive in quite good condition within the areas of the fluvial aggregates deposits (Oakwood Environmental, 1999). It should be noted that wrecks often occupy an extended area beyond the confines of any remaining hull, depending on the circumstances of loss and the effects of post depositional processes. This extended area or debris field may contain significant elements of structure, artefacts and stratified deposits and has to be considered as an integral part of the wreck site. Furthermore, in addition to the potential for shipwrecks of many periods, many areas, especially proximal to historical shipping routes, potentially contain items lost or thrown overboard.

### 3.4 Resource Management

It is clear that issues relating to the management of sand and gravel resources are of high priority both in Ireland and internationally. It is perceived that the principal aim of management strategy in this context would be towards minimising the environmental costs of securing strategic national construction material requirements. Ireland still has no clear regulatory policy regarding the development of offshore aggregate resources, and it is as yet unclear whether these are officially regarded as a legitimate source of commercially accessible construction material or not. The main legislative elements within which

Current Status and RTDI Requirements in Respect of the Development of Irish Seabed Resources 97
management initiatives would be framed are presented below. These are followed by a synthesis of available information on management strategy options from international experience, citing examples from the UK, and those under consideration elsewhere in the EU under the auspices of ICES (WGEXT).

3.4.1 Legislative and institutional management framework

The following National legislation and EU Directives apply:

- Directive 85/337/EEC, which is incorporated into Irish law as EU (Environmental Impact Assessment) Regulations (SI No 349 of 1989).
- Foreshore Acts, 1933 and 1992 (from mean high water mark, to the 12-mile territorial limit).
- Continental Shelf Act 1968 (beyond the 12 mile limit).
- Water Pollution Acts 1977 and 1990 (where the definition of “waters” in section one (1977) includes any “tidal waters”).
- Fisheries (Consolidation) Act 1959.
- Harbours Acts 1946.

In addition the following EU Directives have general relevance but contain no specific requirements relevant to aggregate extraction.

- 76/160/EEC Bathing Water Directive
- 79/923/EEC Shellfish Waters Directive

The procedures currently in operation are based on EU directive 85/337/eeec concerning “the assessment of certain public and private projects on the environment”. This directive is also modified by directive 97/11/EC, which makes reference to the assessment of cumulative effects but provides no terms of reference for implementation within EIAs. In the case of at least one existing licence application for extraction in Ireland (Aquafact International Services, 1997), EIA work has been structured according to EPA general EIA guidelines (1995). For the site concerned off the Waterford coast, approximately 8 yrs have elapsed since the time of first application. During this time the application has proceeded on an inconstant basis with long periods of official quiescence. The proponents have complied with an apparently ad-hoc series of requests for information, and participated in protracted negotiations with the statutory authorities, mediated by consultants acting on their behalf. Authorities concerned have been the DOMNR, local borough council, Fisheries Research Centre (Marine Licence Vetting Committee), GSI, and Duchas. It appears likely that poor coordination between these various authorities may have contributed to the attenuation of the licensing process. Other projects have moved to the implementation phase through a relatively short review procedure that included a limited EIA submission, e.g. Spit Bank in Cork Harbour (Lee Tunnel project). However, in these relatively few ostensibly non-
commercial examples extraction was likely to have been regarded in nationally strategic terms.

3.4.1.1 Status of official licensing policy and procedures

As the competent statutory authority, the DOMNR has final responsibility in the granting of extraction licenses. However, there are at present no policy documents or procedural guidelines aimed specifically at the regulation of marine aggregate extraction in existence. Likewise there are no specific terms to be applied in relation to the design of EIAs, site characterisation data gathering, or monitoring protocols. Indications have been given that these matters are currently under official consideration (submission to WGEXT¹, 2000). The DOMNR have sought (August, 2000) the views of interested parties by means of a briefing document and call for submissions (McGuinn, DOMNR, 2000). That document sets out the current national agenda, reflecting the view within the industry that there exists a need for marine extraction, and briefly lists many of the core issues that should be considered in the development of policy guidelines.

3.4.1.2 Standardisation of application procedures and EIA criteria

The need for clarity in the EIA procedure has been stressed under several previous headings. One means of achieving this in Ireland will be through the initiation of a thorough review process that would rely for guidance on initiatives that are highlighted in ICES recommended codes of practice. It is recognised that this process is likely to be informed by the recent findings of similar initiatives in the UK, Belgium, Denmark, OSPAR and HELCOM. The ICES guidelines were produced in 1992 and are currently in the process of being updated.

Aggregate extraction has been long established in the UK, during recent years about one quarter of national requirements have been successfully met from marine sources (Crown Estates, 2000). Although not finally ratified the current model employed in the UK is highly refined, and encapsulates an enormous amount of relevant experience. Whilst there are differences between UK and Irish administrative systems, much of the UK government view procedure (or a similar or analogous procedure synthesised from some of the wider EU initiatives) could be modified to suit the Irish jurisdictional framework. The criteria for EIAs are a key element of the overall aggregate licensing procedure. Appendix X presents the full text of the UK (2000) schedule of recommendations, as it was presented to the WGEXT during the April 2000 meeting in Gdansk. A summary of the view procedure is presented below.

Government control of UK gravel extraction: The View Procedure

Government control of marine aggregate extraction (dredging) is exercised by means of a Government View Procedure, which is administered by the Minerals and Land Reclamation Division of the Department of the Environment, Transport and the Regions. (The Scottish Office Environment Department and the Welsh Office are responsible in Scotland and Wales respectively.) The Government view procedure is essentially a non-statutory extended consultative process that follows the principles of UK land-based planning procedures. The DETR were working towards introducing a statutory planning procedure in 1999. More details on the forthcoming changes are available from the Minerals and Waste Planning Division of the DETR. There are two main stages of the current non-statutory process:

¹ Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem.
Stage 1: Informal discussions
The applicant commissions a study on the potential effects on the adjacent coastline. If this suggests unavoidable risk, the proposal goes no further. The applicant prepares an Environmental Statement. The proposal is advertised and informal consultations are carried out with local coast protection authorities, fisheries interests, offshore operators, the Department of Transport, the Hydrographic Department of the Ministry of Defence, English Nature and other environmental interests and the relevant minerals planning authorities. Other studies required as a result of these consultations may also be carried out at this stage, e.g. biological surveys.

Stage 2: The government view
A formal application for a dredging licence is prepared by the applicant, taking account of any points raised during the informal stage. On receipt of the application, the co-ordinating department consults with other government departments. Jointly they consider the proposals, representations made and issues related to their specific responsibilities. If government departments agree that extraction should go ahead, a favourable Government view results. The Government view will contain conditions drafted to mitigate any concerns identified during the consultation process. If a department raises an objection that can not be resolved, an unfavourable view will result. It is Crown Estate policy not to issue a licence without a favourable Government view.

What the crown estate does
The Crown Estate now takes no part in the Government view procedure. Only when a favourable Government view is received from DETR does the Crown Estate issue a licence. The Crown Estate stipulates the exact area in which extraction is allowed, the amount of material that can be extracted in one year and the commercial terms. The Government view, which includes all conditions, is incorporated in the licence. The Crown Estate also works closely with MAFF and other organisations commissioning and co-ordinating relevant programs of research and development.

3.4.2 Options for policing monitoring and management
This section will briefly review common approaches to monitoring issues that arise during aggregate extraction activities, as well as examining some more general issues pertinent to resource management.

3.4.2.1 Electronic monitoring systems (EMS)
Electronic monitoring systems have not yet been operated in Ireland for aggregate dredging. However, many of the component sensors that would feed into an EMS are standard equipment on many harbour and channel dredging contract vessels and have a vital operational function in monitoring the efficiency of extraction. The UK experience is again cited as a refined example of how EMS fits into a rational and transparent management scheme. Whilst prospective extraction companies may regard underway monitoring of dredging vessels as an unwarranted imposition, in practice, the data accumulated in this way have been found to be extremely useful in the management of a companies “own” resources, and in assessing operational efficiency.
EMS as part of the UK aggregate management strategy

As a responsible landowner the Crown Estate monitors compliance with dredging licence conditions. Accurate and comprehensive information about where, when and how often dredging is taking place in specific licensed areas is vital to facilitate research into environmental effects. Prior to the introduction of EMS such information was qualitative at best. Since January 1993 it has been a requirement that all vessels dredging on Crown Estate licensed areas must be fitted with an Electronic Monitoring System (EMS) to log all dredging activities. The idea of an EMS for dredgers was first suggested in the 1980s. However it was not until the introduction and widespread availability of the Global Positioning System based on satellites in the early 1990s that the development of EMS became a realistic possibility. The EMS provides an accurate record of the date, time and position of all dredging activities. The position of the vessel when dredging is automatically recorded every 30 seconds, to within at least 100m but more usually 10m accuracy. When the vessel is not dredging a standby signal is recorded every 30 minutes to show that the EMS is switched on.

EMS equipment

Information from up to four Dredging Status Indicators is stored on a dedicated PC. Following each dredging trip the raw data from the PC is automatically encoded and stored on a specifically formatted floppy diskette. Before a vessel is permitted to dredge the design of the EMS has to be approved by the nominated consultants (Posford Duvivier in the UK) and the installation on board the dredging vessel inspected and certified.

Operation of the EMS

New diskettes are supplied to dredging vessels each month and the old ones are returned to the Crown Estate for decoding and analysis (some 500,000 records each month). The records are checked automatically for any breach of licence conditions such as dredging outside area/zone, non-observance of seasonal, tidal or navigational restriction or entry or exit point from a licence. The records are also checked for any malfunctions in the hardware and software and for any gaps in the records when the equipment was switched off without prior formal notification to the Crown Estate. In the case of breakdown the licensee must inform the Crown Estate immediately giving details of the fault and measures being taken to rectify it. If the licensee wishes to continue dredging specific measures to record dredging activity must be agreed at the time with the Crown Estate. A 24-hour fax line has been set up to cover breakdown outside office hours. All breaches of conditions are followed up with the licensee. Irregularity notices are issued immediately the records are decoded requiring an explanation of the breach within 7 working days. All breaches, and the responses from the licensees, are notified to the Department of the Environment Transport and Regions or the Welsh Office along with details of the action taken by the Crown Estate and the licensee.

Output from the EMS

The primary aim of EMS is to monitor compliance with licence conditions. Since its introduction in 1993 records of more than 155,000 hours of dredging from 74 licences, 13 licensees and some 40 dredging vessels have been collected. The EMS records are also used to provide management information both for the Crown Estate and the licensees. Analysis of dredging records over time will build up a detailed picture of dredging which, combined with resource information, will lead to a reduction in the size of licensed areas and zoning to limit the area of seabed disturbed by dredging at any one time. EMS information is also used
during the Crown Estate's annual audit of dredging companies. Individual EMS records are crosschecked against wharf and company records and specific operations can be targeted if necessary. An example of the type of output that can be generated from EMS data is shown in Figure 3.7.
Costs of EMS

The cost of installing the EMS on board a dredging vessel varies between £4,000 and £10,000 depending on the set up, with annual running costs of about £2,000. The cost for the Crown Estate in administering the whole system runs at about £60,000 per annum. To date EMS has cost some £850,000 in total. It is believed that this represents good value for money and demonstrates the ongoing commitment of the marine aggregate industry as a whole to good management and accountability.

3.4.2.2 GIS based marine resource information and management systems

Some form of geographic information system is regarded as an essential pre-requisite to the implementation of cost-effective management infrastructure, both for the administration of aggregate (and other) licensing procedures, but also as a repository and access tool for ancillary geological and biological geospatial information.

Following a period of evaluation during which advice was formally sought from Enterprise Ireland and the CRC, the DOMNR have begun implementation of a GIS strategy based on ArcView. However, it is not known to what extent this system may eventually fulfil an analogous role to that which operates (for example) in the UK system. As the Crown Estates appointees, consulting engineers Posford Duvivier operates the UK system, handling all UK licensing and ancillary geodata, seabed structures, and geological information within the 12 mile limit. It is based on ArcInfo, running on a standard windows NT platform with a customised graphic user interface. A diverse range of systems has been implemented internationally, their features and functionality having evolved in response to local and regional priorities in respect of extraction licensing, and other jurisdictional considerations.
3.5 Potential opportunities for RTDI

3.5.1 Introduction

Of the three main sectors covered in this report, research themes linked to marine aggregate extraction may offer the most immediate potential for research and development. This assertion is based on the following:

- a large total estimated volume of reserves available
- high anticipated demand for utilisation of these reserves
- the low level of current specific research activity in the sector to date in Ireland
- active extraction is underway from the Codling Bank for the Bray beach replenishment project
- a high probability of pilot extraction commencing at the Waterford site in the near future

There are now a very significant number of parties in Ireland with an interest either directly or peripherally in marine sands and gravels (McGuinn, DOMNR personal communication). A forum held in Cork during 1998 as part of the MRM Reconnaissance assessment project was attended by 30 participants representing all the key interest groups including commercial aggregate companies, Dúchas, GSI, fisheries interests (FRC) and other scientific and lay interests. This is particularly the case in view of the increased convergence between geological and biological approaches to coastal seabed characterisation that is increasingly recognised internationally (EMSAGG\(^1\), 2000; ICES WGEFT, 1997, 1999 & 2000). This convergence also exists within the Irish research community, as was clearly demonstrated through discussion and feedback arising at the national seabed survey forum in Athlone (Marine Institute, 1999) and Dublin (GSI, 2000). At present there is no specific co-ordination or formal liaison between these various groups and individuals. Thus there would appear to be a role for a clearly identifiable organisation to co-ordinate the various strands of existing and future research of relevance to the field on a national and international basis. Benefits such as standardisation of methodologies and descriptive terms in relation to seabed facies, and biotopes, as well as common approaches to zonation linked to ICZM are seen as direct and very necessary outcomes. A further possible function of such an organisation would be to liaise, and arrange partnership agreements between (say) academic institutions, state sponsored bodies and commercial operators in order to achieve maximum efficiency and co-operation, particularly with respect to costly equipment mobilisations and sea time.

There is an extensive list of international research topics associated with marine aggregates, offering considerable scope for increased Irish participation that might fall into the following two general categories.

- Increased provision of specialist domestic RTDI skills and equipment to participate in existing overseas programs, e.g. through EU partnership programs, EU5FP, and INTERREG, as well as specific tendering for private research commissions such as those undertaken by CIRIA (EMSAGG).
- Development of new, predominantly domestic research programs involving inward transfer of techniques, skills, and equipment in order to focus on more localised conditions. These would eventually feed back results contributing to policy formation at the international level.

\(^1\) European Marine Sand and Gravel Group.
An existing model for this type of approach can be found in the European Marine Sand and Gravel Group (EMSAGG), which was established in 1998 under the auspices of CIRIA in the UK.

3.5.2 European Marine Sand and Gravel Group (EMSAGG)

EMSAGG is an international group made up of organisations spanning an area of interest from the Atlantic to the Baltic. Membership of the group includes national governments, regulators, dredging and aggregate companies, conservation bodies, academics and research institutions. EMSAGG was formed in 1998 after research work looking at marine sand and gravel in NW Europe identified the need for international collaboration in the study of issues that effect marine sand and gravel extraction in the study area. The group was established on a not-for-profit basis with CIRIA acting as secretariat to co-ordinate meetings and produce the group’s bulletin. The group meets twice a year to share information and to discuss its research objectives. Issue 3 of the EMSAGG bulletin will be released in early 2001, and will contain a report of the November 2000. These bulletins provide information pertinent to the marine sand and gravel industry within Europe on the following subjects:

- major projects and schemes
- research and development progress and new projects and proposals
- published reports and recent publications
- data and information sources
- techniques for measurement and interpretation (tools)
- changes in policy and legislation
- environmental issues.

3.5.3 International priorities as outlined through WGEXT

An overview of international priorities for an aggregate linked RTDI agenda as described in the WGEXT draft report (2000) is presented the following:

Draft Resolution 1: Future meeting of WGEXT

The Working Group on the Effects of Extraction of Marine Sediments on the Marine Ecosystem [WGEXT] (Chair Dr J. Side, UK) will meet in Copenhagen from 3-6th April 2001 as guests of the ICES Headquarters in order to:

1. Review data on marine extraction activities, developments in marine resource mapping, information on changes to the legal regime (and associated EIA requirements) governing marine aggregate extraction, and review scientific programmes and research projects relevant to the assessment of environmental effects of the extraction of marine sediments. National reports to be provided electronically no later than 16 March 2001;

2. Continue work (taking into account relevant work under and requirements of OSPAR and HELCOM) on the updating of:
   - the ICES Code of Practice for the Commercial Extraction of Marine Sediments (including minerals and aggregates), produced in 1992.
   - guidelines for the preparation of an Environmental Impact Assessment evaluating the effects of seabed aggregate extraction on the marine environment, including as
appropriate guidelines on monitoring and standardised procedures, reviewed most recently in 1998 for inclusion in the forthcoming ICES Co-operative Research Report. In taking forward the production of draft ICES guidelines, WGEXT will review draft guidelines tabled at the last meeting by the UK, Denmark and once available Belgium, HELCOM work and other guidelines being developed by other ICES members. WGEXT will endeavour to produce a draft set of revised ICES guidelines at this meeting;

3. Commence work on developing criteria for the selection, design and operation of a series of test ranges in the offshore in order to:
   - assess the capability of Acoustic Ground Discrimination Systems (AGDS) for detecting and delineating biological communities
   - compare and contrast the relative resolution and capability of AGDS with conventional side scan sonar, multibeam and high resolution seismic methods
   - determine the relative resolution, operational parameters of AGDS and conventional mapping systems in a variety of water depths and substrate types, primarily focusing on habitats relevant to aggregate extraction activity
   - determine the need for testing/intercalibration ranges in ICES member countries taking into account the role of the manufacturers in testing their equipment;

4. Examine the methods that might be used to assess localised impacts from aggregate extraction on fisheries, and the means to adequately protect known herring spawning beds in the vicinity of extraction operations;

5. Undertake a review of reference site datasets used in the monitoring of, and in research on, the effects of aggregate extraction in order to establish their usefulness in determining the degree of natural variability in biotopes;

6. Review conclusions drawn from the completion of biological monitoring of the Øresund fixed link with a view to applying this knowledge to other large-scale extraction projects.

**Priority Issues at WGEXT**

The current activities of the Group are concerned with developing understandings necessary to ensure that marine sand and gravel extraction is managed in a sustainable manner, that any ecosystem effects of this activity are better understood so that mitigative measures can be adopted where appropriate. These activities are considered to have a very high priority and have the following scientific justification:

a) An increasing number of ICES member countries undertake sand and gravel extraction activities, while others are looking at the potential for future exploitation e.g. Ireland and Canada. Each year WGEXT reviews relevant developments under these headings and includes a summary of them in its report. This provides a forum for information exchange. In order to maximise time spent discussing other topics; this is conducted in advance and circulated as a draft prior to the meeting.

b) This is a response from WGEXT to a number of recent requests and the recognition that these documents should take into account Annex V of the 1992 (OSPAR) Convention on the Protection of the Marine Environment of the Northeast Atlantic, and other developments, for example, in strategic environmental assessment.
c) WGEXT has been reviewing new technologies and techniques for the study of seabed sediments and benthic habitats in relation to its core focus on marine sediment extraction. While it has an interest in marine habitat classification and mapping more generally, this work is concentrating on scientific applications to assessment of environmental effects (and determination of vulnerable habitats) associated with marine sediment extraction. Discussions at WGEXT 2000 identified that several countries are conducting studies to establish the scope and limitations of AGDS in comparison to more conventional acoustic techniques. This would be a timely review of a rapidly developing subject.

d) While in recent years much effort has been directed to the observation of effects on the marine benthos, WGEXT has on several occasions examined effects at higher trophic levels and on fisheries. Discussion at WGEXT 2000 focused on identifying means to identify herring spawning habitat. However, during the meeting the means to adequately protect such habitats from localised effects of aggregate extraction was raised as a subject worthy of further attention. Additionally, there were several requests to examine the methodologies used to assess localised impacts of extraction operations on fisheries more generally.

e) Many monitoring studies and research projects being conducted by ICES members have been undertaken to identify the impacts of sand and gravel extraction on the seabed. The reference site data from these in some cases show little variation year on year, in other cases significant changes have been detected. This data may be useful in assessing natural variability in some marine biotopes, and hence in the design of future environmental monitoring programmes for marine sediment extraction.

f) The completion of biological monitoring on this project enables a critical review of such data in relation to other proposed large scale extraction projects. Reports were not available to WGEXT 2000 but will be published very shortly and hence the Working Group wishes to carry this term of reference over to its next meeting.

- Relation to Strategic Plan: The principal focus of WGEXT work is in relation to Objective 2(c), but other terms of reference also relate to Objectives 1(a), 1(c), 1(e), and 4(a) above

- Resource Requirements: Most countries routinely collect data and information on their extraction activities which will be collated and contribute to item (a). The UK and Denmark have recently developed guidelines and Belgium is currently developing guidelines (to be circulated in advance of the meeting). Resources have already been committed to develop such guidelines.

The research programmes that provide the main input to item (d) are currently underway and resources already committed. The following linkages are recognised:

- Linkages to Advisory Committees: Advisory Committee on the Marine Environment
- Linkages to other Committees or Groups: Benthic Ecology Working Group, Study Group on Marine Habitat Mapping
- Linkages to other Organisations: Work is of direct interest to Convention for the Protection of the Marine Environment in the North Atlantic (OSPAR), Working Group on Seabed Activities (SEBA) and Working Group on Impacts on the Marine Environment (IMPACT), and Helsinki Convention (HELCOM)

Current Status and RTDI Requirements in Respect of the Development of Irish Seabed Resources 107
3.5.4 UK strategic research priorities

The following list of research themes follows recommendations made by the CIRIA report (presented at the last WGEXT meeting) and gives a view of priorities from a UK perspective. Most if not all of these themes are considered to be of general relevance in an Irish context, although it will be important to differentiate between findings that apply only to specific sites or localities, and those with potential for global application.

- Development of a comprehensive assessment framework
- To adopt an assessment framework that indicates the method steps required to make an assessment and the information required to inform decisions.
- Fill the knowledge and technology gaps in the assessment process through research, development and monitoring
- Produce good practice guidelines on the assessment of sediment plumes.
- There is a need to be able to comprehensively describe the turbidity plume. This requires better quality baseline data and improved modelling techniques. To be cost effective, it is necessary to develop predictive techniques that can be used to assist in determining the acceptability of a particular operation.

Other recommendations include:

- Development of an internationally accepted monitoring protocol
- Field testing suspended sediment monitors
- Determine a standard procedure for measuring the disaggregation index
- Monitoring benthic boundary processes
- Monitoring environmental effects
- Filling gaps in modelling capability
- Developing best practice guidance for assessing environmental effects
- Understanding environmental effects (prediction and field monitoring)
- Guidance on the assessment of sediment plumes: impact prediction
- Development of an indicative environmental effects framework

Research and Development

The Crown Estate and MAFF are extending their joint research program for a further three years. During this time, an experimental site and associated reference sites will continue to be sampled every year until dredging-related changes have stabilised. Fish populations in the vicinity of aggregate areas will also be sampled and their feeding preferences determined through analysis of stomach contents. The information can then be used to assess how commercial dredging affects the seabed food resource in different areas and whether these effects change with the seasons. Another widely expressed concern relates to the effects on marine life of sediment plumes. This topic will be addressed through field investigation of plume dispersion coupled with experimental systems for exposing selected organisms to different concentrations of waterborne particles. The results will also be examined alongside data obtained from field sampling of the same species in areas predicted to be affected by such deposition. Finally the geographical scope of a study aimed at characterising the marine life inhabiting gravel deposits near areas of commercial interest will be extended and quantitative techniques employed.
3.5.5 Aggregate prospecting and resource quantification

Although still a requirement shared by the all nations already involved in extraction, this area of research can be regarded as high priority in view of the large number of gaps and lack of resolution in the quantification of the national resource. The first line of approach is already seeing the innovative use in Ireland of existing and newly emergent technology developed elsewhere rather than the use and development of indigenous technology. There is a need for rapid, cost effective systems to collect profiles and conduct appraisals of upper sedimentary layers. Some systems are now available in Ireland through the national equipment pool, whilst other important items have to be hired in, usually from the UK. Appropriate matching of equipment with the desired survey and research objectives is vital. A highly detailed review of this topic from a biotope perspective is contained in the final report of the Nearshore Ecosystem Database Project commissioned by California Dept of Fish & Game (Kvitek et al., 1999), and is also currently under review by ICES WGEXT.

3.5.5.1 Bathymetric measurement

Accurate, high resolution, cost effective survey systems are required. Some true multibeam sonar systems are now becoming available in Ireland, such as that installed in the Celtic Voyager, and a further (deepwater) system is due to come on stream with the arrival of a second research vessel. The increased use of swath bathymetric systems in the offshore is highlighting the need for methods to ensure accurate and simple tidal reductions. The lack of a national tidal gauging and archiving infrastructure is currently a hindrance to many offshore operations. Potential innovations in this area will be the deployment of tidal buoys fitted with Real Time Kinematic GPS equipment for collecting offshore tidal data, as well as conventional sea-bed mounted pressure type recorders. Obvious overlaps in objectives will be encountered with respect to the national seabed survey but many opportunities for complementary or ancillary work remain given the 50m cut-off envisaged for the bulk of work to be carried out under the national survey.

3.5.5.2 Sediment characterisation techniques

Complementary to the acquisition of high quality bathymetric data is the requirement for sediment characterisation. This is accomplished either through direct sampling or indirect (usually) acoustic techniques. Most remote sediment classification systems work by measuring variations in the properties of returning acoustic signals. They accomplish this, by employing algorithms to perform wave-form analyses that track changes in wave characteristics as a function of seabed roughness, and reflectivity. Side-scan sonar systems produce digital and analogue, shaded imagery with varying degrees of brightness scaled to register the degree of acoustic backscatter ensonified at any one time. Similar seabed imagery is produced by multibeam sonars during the acquisition of bathymetric measurements. Considerable skill and operator experience are required in the collection and interpretation of these image types, however, under suitable conditions seabed bedforms and seabed facies can be accurately and effectively inferred over wide areas. Other systems such as RoxAnn (originally developed and currently operated in Ireland), Echoplus (2nd generation RoxAnn), and QTC-View are classed separately as Acoustic Ground Discrimination systems (AGD). These work in a different way by processing return signals in a "black box" to produce an instantaneous assessment of sediment type and thus do not necessarily require interpretative input from an operator. However, it is emphasised that all methods of remote determination of sediment type are inherently reliant on correlation with physical seabed samples/and or visual methods in order to ground truth inferred acoustic facies.
Physical sampling of the seabed is fundamental to all aggregate resource assessments. This can be accomplished using a wide variety of existing sampling devices, and is usually carried out in conjunction with remote methods in order to ground truth results. Accurate location and quantification of resources requires high-resolution methods to resolve sedimentary units in at least the upper 20m below the seabed. Usually this is achieved by acoustic means with boomer or sparker 2-D seismic reflection, again backed up with ground truthing in the form of vibro or other physical coring techniques. These acoustic systems will return data in most sediment types, though penetration and resolution can be poor in resistant gravels due to energy dissipation off multiple surfaces. Currently, there are no boomer systems available in the national equipment pool, and these have to be hired in from the UK. A “chirp” system belonging to the national pool has been recently deployed in the Waterford area, and preliminary results are promising although penetration is limited in the more compacted sands and gravels. Further evaluation in these sediment types is required. A range of innovative techniques has appeared in the last year that could provide specialist solutions to surface sediment definition. The following examples are presented.

1. Shallow water compact 3-D seismic method for detailed site investigation. This project aims to develop a detailed reconnaissance method of analysing seabed sediment properties for geological, geotechnical and environmental site investigation purposes based on very high resolution 3-D seismic techniques. It is funded by the EU, and is a joint project between IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer, Universiteit Ghent, Ecole des Mines, Paris, Osservatorio Geofisico Sperimentale, Italy, University College of North Wales, UK, and Hydrosearch Associates, UK). Prototypes of both the rigid shallow (20m) and flexible deep-water (to 100m) systems have been tested. Preliminary contacts have been made and there are opportunities to develop collaborative links in this area.

2. Continuous refraction seismic profiling (CRISP). This is a new high-resolution technique used to produce details of sediment characteristics particularly in "difficult" areas including shallow water, coarse or cemented material (Anderson, 2000). CRISP is developed and operated by Fugro Survey Pty. Ltd. Australia, who have signalled their intention to make a unit available for use in Europe.

There is a broad range of possibilities for development of innovative ways to integrate information from all of the sources described. Fully 3-D & 4-D GIS systems will be required to manage data and reveal complex temporal and spatial patterns. Off-the-shelf systems are available but there are likely to be many specialist applications requiring a customised approach.

3.5.6 Coastal systems research

Basic and applied research on coastal systems has been undertaken in Ireland for some years, and a platform of expertise has been established at a number of centres throughout the island both north and south. Considerations associated with removal of coastal sedimentary material are likely to provide a considerable stimulus to deepen elements of this research in response to particular license applications. However, it is important to recognise that coastal sedimentary systems are complex and often have pathways and linkages far beyond the immediate area of interest. Comments made at the start of this section are particularly relevant to these issues, as a co-operative approach will be required to ensure that regionally integrated long-term solutions are targeted in favour of local fixes. Although not necessarily
linked with aggregate extraction *per se*, there are many examples particularly from the UK east coast of problems ensuing in areas quite remote from the original site of activity. A large initiative is currently planned to examine various aspects related to this field through recent HEA funding initiatives in Cork. There are likely to be many spin-offs from this fundamental work. Project development under this theme would be consistent with a proposal currently under consideration at EMSAGG entitled: *Guidance on selecting methods for seabed sediment transport studies for dredging areas* (EMSAGG, 2000).

### 3.5.6.1 Predictive modelling of sediment transport paths

The focus of this theme is on hydrodynamic controls on coastal sedimentary cells within the context of wider coastal circulatory systems. Physical and mathematical models will be required to aid in the prediction of potential scenarios resulting from alteration of seabed conformation due to the effects of extraction. These effects can be manifest in terms of alteration of wave climates, circulatory systems, and in habitat modification. Other areas of linked research include studies on erosion dynamics, hydrosedimentary modelling, and the impacts of low frequency, high energy events.

### 3.5.6.2 Oceanographic observations

This theme is closely linked with the previous one; here however, the focus is on acquisition of physical field measurements that are required to validate and calibrate the range of models described above. In many cases comprehensive suites of field measurements will be collected in association with actual trial dredging operations to constrain temporal and spatial variation in critical parameters. These will include programs for the collection of current meter data, sediment traps and remote observations, drogue tracking and a range of more specialist observations related to plumes. New techniques are becoming available to undertake particle size measurements *in situ*.

### 3.5.7 Sustainable resource management

Many of the options for long-term sustainable resource management discussed in previous sections may be directly applicable in an Irish context with respect to an emerging aggregate extractive industry. Others may require modification to suit localised conditions, thus providing a range of RTDI opportunities. Emphasis is placed on examining the cumulative effects of extraction, particularly on areas where extraction might be concentrated on a number of closely spaced or intersecting licence blocks. Some specific examples are described below.

#### 3.5.7.1 Specialised software and hardware development

The details of electronic monitoring systems have been fully described in previous sections. Despite availability of systems elsewhere, such as system could be developed locally, with the potential to integrate enhancements not available on generic models. It is very unlikely that extraction would go ahead in Ireland without some form of monitoring being implemented. Not only would the benefits already outlined above be realised, but also additional advantages would accrue in terms of a highly visible means to allay public concerns and misconceptions relating to purported “unrestrained strip-mining of the ocean floor.”
Conceptually linked to EMS but further downstream in the management process, are expert system predictive models. Here the emphasis is on the use of intelligent systems to formulate solutions in situations where there are multiple disparate data sources. The development of "data reservoirs" based on fuzzy logic rule based expert systems, can accrue advantages of standardisation of data for smooth exchange between governments, NGO's, research groups and individuals. These systems take account of imprecision within a database, and can deal with qualitative data when used in conjunction with issue analysis. An example of this type of system is Simcoast, produced at Fugro Geos UK by Dr Ann Novello Hogarth.

Coastal and Ocean Zones Display and Information Systems (COZDIS) are dynamic digital coastal and oceanic information charts that combine 4-D environmental data to create environmental scenarios adaptable to a wide range of uses providing value-added information.

3.5.7.2 Ecological modelling

The key issues that should be considered as part of the licensing and EIA process have been framed in considerable detail in previous sections. Continued progress in the development of a marine aggregate industry will imply significant investment in programmed research, assuming that procedural scope and format to adopted in this country will be consistent with ICES recommendations. Although some of the datasets generated will be proprietary and confidential to a prospective developer, it is hoped that protocols can be put in place to ensure as much data as possible reaches the public domain in timely fashion. This may be facilitated by arrangement of a set time period to allow commercially sensitive information to “cool-off” prior to dissemination. This supply of environmental data would undoubtedly provide scope to further enhance and extend ecological modelling work already being conducted under several existing EU and INTERREG funded programs. The types of approach that have been adopted elsewhere particularly with respect to the assessment of cumulative effects include: questionnaires/checklists/matrices; cause and effect analysis; ecosystem, economic and social impact analyses and synoptic approaches; definition of temporal boundaries; and definition of resource thresholds.

3.5.8 Estimates of existing (terrestrial stocks) and projected future demand

Work is currently underway at the GSI to undertake a full resource inventory of land based aggregate stocks. It is planned that the results of this study will be incorporated into a GIS although it is expected that results might not be available for some time, as extensive fieldwork is required to evaluate individual quarries. Given the strategic importance of this resource in maintaining the momentum of infrastructure development, it may be prudent to accelerate this initiative through the allocation of further resources. An initiative of this nature would complement proposals currently under development by EMSAGG (Proposal no. 1674: *A Proposed Methodology for Examining the Supply and Demand for Marine Sand and Gravel in North West Europe*; & proposal no. 1675: *The Potential Impact of Alternative Materials on the Demand for Marine Sand and Gravel*). Comparative nationally orientated socio-economic studies are also required to evaluate relative environmental impacts, as well as social and economic aspects of terrestrial and marine aggregate extractive industry. These would include domestic studies of relative energy consumption and emissions during dredging and transport of land and marine resources.
3.5.9 Summary of Aggregate related RTDI

The following points summarise the key thematic areas for development of RTDI projects associated with the sustainable development of offshore aggregate resources from Irish coastal waters:

- Inauguration of a representative body to act in liaison with MI, relevant statutory and non-statutory bodies, academic and other institutions and public representatives.
- Continued and enhanced support for existing areas of research including sedimentological studies, environmental modelling, biotope and seabed mapping, databases, GIS.
- Development of new programs based on Irish and international priorities including establishing standardised management and review procedures, and investigation of cumulative effects.
- Increased involvement in ICES WGEXT and development of networking links and co-operative committees in unison with UK, French and other neighbouring countries with interests in the field e.g. through EMSAGG.
- Increased involvement in all EU commission backed research associated with aggregates
- Detailed investigation of use of innovative techniques for resource evaluation, and the potential for joint industry programs.
- Development of detailed package of priorities with respect to potential extraction areas in relation to established conservation strategies, establishment of buffer zones.
- Research and development of suite of monitoring protocols and sensors.
- Development of higher resolution hydrodynamic models leading to improved predictive capacity and better understanding of coastal systems.
4 Other minerals

4.1 Orthogenic Phosphate

4.1.1 Current international experience with respect to the exploration and development of orthogenic phosphate resources

Phosphate is an important nutrient essential for marine biological activity. Where biological productivity is high, excess phosphate may not be fully metabolised and hence become precipitated or geologically fixed. This can occur where cold bottom-waters, often enriched in nutrients, upwell to the surface. The upwelling often causes a high degree of biological activity allowing significant amounts of biological phosphate to settle to the seafloor on the continental shelf break. If the pore-water in the sediment has a low dissolved-oxygen content, the unoxidised organic detritus is eventually transformed into phosphite.

Orthogenic phosphate or phosphite can occur in phosphate-bearing compounds that occur abundantly as a precipitate in nodules or as a thin crust on the continental shelf or on banks at depths between 100m and 1000m. Concentrations of phosphates ($P_2O_5$) in such concretions can reach 30% by weight, with a growth rate of 1-10mm$^{-3}$a. Most deposits are of Miocene age, reflecting favourable environmental conditions pertaining at that time. Significant reserves exist of large deposits of phosphite off California, Peru, Mexico, Australia, Japan, Morocco and Namibia. All of these deposits are found in the mid/low-latitudes, in areas where major upwelling occurs. Phosphite also occurs along the eastern seaboard of the US, where it is associated with upwelling on the edge of the Gulf Stream on the Blake Plateau. The upwelling facilitates high fallout of phosphate-rich faecal pellets to the seabed where it is converted to apatite (calcium fluophosphate) by biochemical processes. In Onslow Bay, North Carolina, eight beds of phosphate have been discovered of which five are economic. It is estimated that 3 billion metric tons of phosphate concentrates exist in this accumulation alone.

Phosphates can also occur as phosphatic muds and sands in shallow waters where biological productivity is high. Concentrations of phosphate by weight in these deposits are typically 12% to 18%.

Phosphates are valuable as fertilisers with land-based sources almost exclusively consisting of former marine sediments or guano. It is estimated that 50 billion tons of phosphate exists in the world’s oceans. There is, however, no shortage of land-based supplies that are at present relatively cheap to extract. Production is controlled by a few nations making strategic mining politically expedient for some countries. It is unlikely that any offshore mining will occur in the near future. The first reserves to be mined are likely to be off the coast of Florida or the Chatham Islands near New Zealand.

4.1.2 Synthesis of extent and recoverability of orthogenic phosphate in Irish waters

There are no known accumulations of orthophosphate in near-surface Irish marine sediments due to a lack of high biological productivity of a scale commensurate with upwelling areas.
or shallow tropical seas. To a certain extent, it can be argued that Ireland exists at the wrong latitude for phosphite formation.

Nevertheless, were any phosphite to be found in Irish waters it is unlikely that the accumulations would rival other international reserves. Furthermore, as terrestrial reserves are still plentiful, it is unlikely that phosphite will ever represent a significant marine mineral resource for the Irish economy.

Members of the Geological Survey have in the past been involved in an assessment of possible concentrations of phosphite off the coast of Co. Clare. These deposits are believed to have been derived from the reworking of landbased geological phosphites formerly outcropping near Liscannor at the boundary between the Lower Carboniferous and Namurian (M. Geogheghan, *personal communication*).

**4.1.3 RTDI initiatives associated with orthogenic phosphate**

In view of the low reserve potential, and the absence of any obvious economic or strategic incentives, it would not be expedient for Ireland to invest significant money in any prospecting for these minerals in Irish waters. There may be some limited return in tracing the viability of submerged phosphate-rich geological formations under water near to the coast. For example in the case that further work is programmed in proximity to areas already suggested to contain deposits, their potential existence can be flagged for supplementary inclusion.
4.2 Methane - Hydrate (Clathrate)

4.2.1 Current international experience with respect to the exploration and development of methane-hydrate resources

4.2.1.1 Formation and occurrence of methane hydrates

Methane hydrates are a type of natural formation that contains large amounts of methane and water in the form of a solid ice-like matrix. Formation occurs under moderate pressure and at temperatures that are low but above the freezing point of water. Stable methane hydrates are found at the temperature and pressure conditions that exist near and just beneath the sea floor where water depths exceed 300 to 500 meters. Hydrates are plentiful in nature, both underwater and under permafrost, Figure 4.1 shows the basic phases for the existence of hydrate with respect to temperature and pressure. While they are a potential source (and possibly a very important source) of energy for the future, little is currently known about cost-effective ways to turn hydrates into an energy resource.

![Figure 4.1 Phase stability field for methane hydrate](image)

The following two basic classes of hydrates are recognised:

1. Biogenic hydrates (formed through bacterial action) may form relatively slowly, as bacteria digest detritus that has sunk to the seafloor over a wide area. It is believed that this non-concentrated bacterial action results in formations in which hydrates are relatively evenly distributed throughout other rocks or sediments. If detritus is concentrated, however, hydrates of biogenic origin can form layers that may be mixed in
with or separated by sediments. These dispersed hydrates are less likely to be of economic potential.

2. Thermogenic hydrates (formed when methane and other gases vent from depth) are likely to be more concentrated than biogenic hydrates and hence are of more economic significance. These hydrates are often associated with gas escape along faults, mud-volcanoes, or to a lesser extent, pock-mark fields. They may form mounds on the seabed, or spread out from escape structures, effectively sealing them, preventing more methane from rising to the surface, or they may form subsurface concentrations enriching biogenic hydrate accumulations.

Differences among hydrate-containing formations may also result from geological events that occur after the hydrates are formed. Any one (or a combination) of the following events may account for formations in which free methane is trapped beneath hydrates:

1. Layers may melt. As hydrate layers pile up and become buried in sediment, the lowest layers may be pushed down so far that they are warmed by heat from the earth's core and melt, forming free methane and water.

2. Layers may melt and reform many times. Disturbances such as earth tremors may move layers into and out of the "hydrate zone" a number of times. Or seasonal or climatic warming of water may cause layers to melt. In these cases, hydrates may fill the pore space in sediments so thoroughly that they effectively seal them.

3. Layers or mounds may seal a fault or mud volcano. A hydrate deposit near a vent may close off further escape of gases. This is not always the case, and gas escapes are documented from faults that continue up through the hydrate deposit, or discharge episodically from mud-volcanoes.

Hydrates have potential as a future energy resource (in nature, 1cm$^3$ of methane hydrate yields >158cm$^3$ of methane). For purposes of producing natural gas from hydrates, the concentration of hydrates within a formation is important. It would be much more expensive to produce gas from hydrates that are, for instance, evenly distributed at low percentages throughout a mud formation than it would be to produce from a formation with a very high percentage concentration in one place, possibly with free methane trapped beneath it. Current geological consensus indicates that deposits formed through underground venting will prove the easiest to recover because of their localised and concentrated nature. Additionally, there is a higher probability that hydrates formed at vents will have free methane trapped underneath them.

Three-dimensional seismic data provides preliminary identification of some hydrate deposits both at and underneath the sea floor. Seismic exploration techniques frequently detect not the hydrates themselves, but the bottom of the hydrate deposit and the beginning of a zone of free methane (Bottom Simulating Reflector or BSR). The BSRs are often located at 500 to 800m below the seafloor. Figure 4.2 shows the position of the hydrate stability zone in the upper sediment, and Figure 4.3 shows the appearance of a BSR in a seismic section.
Figure 4.2 Position of the hydrate stability zone in the upper sediment, after Max and Chandra (1998). Heat rising from below is transferred into the cold sea water. Base of Hydrate Stability Zone (HSZ) is the phase-boundary. Representative hydrothermal and geothermal temperatures shown.
Figure 4.3 Seismic section of the Blake Outer Ridge showing strong BSR (bottom simulating reflector of gas below hydrate). Supplied by W. P. Dillon, USGS.
4.2.1.2 Methane hydrates as an energy source

It is beyond question that there are extremely large amounts of energy are locked up in hydrates:

“The amount of methane held in the form of gas hydrates world-wide is estimated to be at least 10,000 gigatons of fixed carbon,”.

“Estimates of methane volumes are converging on about a factor of two larger than the methane equivalent of all known fossil fuel deposits (coal, oil, and natural gas)” (Kvenvolden, 1993).

While costs of hydrate production are still speculative, they are almost certain to be higher, at least initially, than the costs to produce conventional natural gas. Producers would have a difficult time recovering those costs because, once on the market, gas from hydrates is indistinguishable from conventional gas and would thus sell in competition with it, and at the same price. The economic imperatives of hydrate resource recovery may be significantly different for countries like Japan and India, which have very few energy resources, which are concerned about the price and national strategic problems associated with energy importation. These countries see a potential for significant economic gains if they could tap a domestic energy resource. It appears likely that some resources are recoverable. However, scientists urge caution until production feasibility is carefully assessed. Statements such as the following are common in research reports:

"Recoverability of gas from these deep marine structures, however, is very problematical at this stage. Important constraints such as permeability are not taken into consideration [in this study], but new drilling technology, such as horizontal drilling through the reservoir to enlarge the drill hole face area, may compensate for the low permeability normally found in marine sediments." (Max & Lowrie, 1992)

"It is possible that the volume of gas in the world's hydrate reservoirs exceeds the volume of known conventional gas reserves. However, the resource estimates include numerous assumptions that need careful testing, such as the concentration and extent to the hydrate accumulations. Moreover, little work has been performed on the production potential or the economic feasibility of gas hydrates."

"While the published estimates of methane hydrate abundance are enormous, it is likely that most of the hydrate occurs in low concentrations and has no commercial potential.” (Johnson, 1998)1.

4.2.1.3 International research initiatives

The US, Japan, India, Canada, UK, Brazil, Norway, and Russia all currently have active research programs in methane hydrate. Several of these countries are expected to propose co-operative work and scientific exchange, as the U.S. program becomes active. A US Government funded hydrates program was terminated in 1992 because of the belief that it was not making significant progress and that it was largely unneeded in the foreseeable future.

future. However, research continued at a number of U.S. academic institutions, funded in part by the oil and gas producing industry. Several federal agencies including: the National Oceanic and Atmospheric Administration; the Naval Research Laboratory; the Minerals Management Service; and the U.S. Geological Survey all conduct ongoing hydrates research directly connected to their missions. Following US Congress legislation a very comprehensive gas hydrate R&D program was established. The full plan for this program is available from the US Dept of Energy\(^1\), and the executive summary is reproduced in Appendix XI, (U.S Dept of Energy, 1999).

Japan is expected to spend about $50 million on methane hydrate production research. As part of the Japanese effort, Japan National Oil Company drilled a gas hydrates well in the Mackenzie Delta, Canada, in February-March 1998. DOE and USGS researchers participated in experiments at the well and are currently studying samples collected there. India has allocated $56 million for a gas hydrates program to collect and interpret new seismic data and develop new production technologies. India, through the Gas Authority of India Ltd. (GAIL) and the Indian Institutes of Technology, has also initiated a program to offer offshore leases for methane production from hydrates. Indian officials have expressed their intention to fund gas hydrate work by NRL, USGS and other U.S. scientists.

Collett & Ginsberg, (1997) report that gas trapped below hydrate deposits on land is currently being produced at Messoyakha in Western Siberia, and Senior (1990) describes the recovery since the 1960’s of methane from hydrates using pumped methanol from the same area. Recovery tests of methane from similar gas hydrates in the Prudhoe Bay field of Alaska have yielded methane recovery rates similar to those in Russia. Recent drilling in a permafrost hydrate in the vicinity of the Mallik well in March 1998 in the Mackenzie delta of northern Canada proved a significant resource of 42.5 million cubic metres per km\(^2\) (Collett & Dallinmore, 1998).

Commercial drilling of marine hydrates has not occurred to date although drilling for scientific purposes, or by accident is documented. One of the best-known oceanic gas-hydrate occurrences was specifically drilled for the Ocean Drilling Program in the Blake Outer Ridge along the SE US coast (Max & Dillon, 1998). This area may contain an enormous quantity of methane in one continuous deposit. Research into the potential of hydrates is expanding with the EU and other countries having now begun to program hydrate research funding (Max, 1999).

### 4.2.1.4 Extraction of methane

Extraction of methane from the solid hydrate form must include a process of prior disassociation or gasification. Three main techniques for secondary recovery are described. The first two are applications of techniques used elsewhere in the hydrocarbons industry and involve thermal stimulation in the first case, either by injection of hot fluids and steam, or by the application of \textit{in-situ} thermal sources. In the second case hydrates are rendered unstable through injection of brines or other chemicals. The third method (unique to hydrates) involves depressurisation. Free methane gas is removed from the hydrate system causing a reduction in pressure. This in turn causes solid hydrate to become unstable at the phase

\(^1\) http://www.fc.doe.gov/oil_gas/methanehydrates/99hydrate.pdf
boundary and liberate more gas, which draws geological heat from below continuing the process. A combination of these techniques may ultimately prove to be the optimum production solution (Max, 1999).

4.2.1.5 Links with climate

As well as energy production related issues, gas hydrates are also significant in other fields of interest. Hydrates are a source and sink for atmospheric methane. Better understanding of these natural deposits may increase our understanding of climate change. Methane bound in hydrates amounts to approximately 3,000 times the volume of methane in the atmosphere. Methane is 10 times more effective a greenhouse gas than CO₂ and gas hydrates may contain three orders of magnitude more methane than exists in the present day atmosphere. Because hydrate breakdown causing release to the atmosphere can be related to global temperature increases, gas hydrates may play a role in global climate change. There is insufficient information to judge what geological processes might most affect the stability of hydrates in sediments and the possible release of methane into the atmosphere (methane is released as a result of destabilisation caused by isostatic pressure changes associated with sea-level changes[positive or negative]or from gas hydrates in Arctic sediments warmed by increasing ambient temperatures as a feedback loop in climate change). The resultant global warming might counteract other cooling trends and thereby stabilise climatic fluctuation, or it could exacerbate climatic warming and thereby further destabilise climate. The contribution of hydrates to global climate change has not been quantified, though this has been discussed by various authors (Dillon et al., 1988). It has also been suggested that impact generated shocks caused by bolide collision with Earth in the late Cretaceous may have caused sudden blow-outs of large volumes of methane. If it had ignited and combusted in a firestorm a positive thermal feedback would have led to further long-term methane release in a disturbed ocean-atmosphere system. (Max et al., 1999).

4.2.1.6 Sediment stability

Hydrates affect the strength of the sediments in which they are found especially when destabilised to create a layer of buried free methane. Areas with hydrates appear to be less stable than other areas of the seafloor. Consequently, it is important to assess their presence before the construction of underwater structures related to gas and oil exploration and production. Seafloor slopes of 5 degrees and less should be stable on the Atlantic continental margin, yet many submarine slide scars are present. The depth of the top of these scars is near the top of the hydrate zone, and seismic profiles indicate less hydrate in the sediment beneath slide scars. Available evidence suggests a link between hydrate instability and occurrence of submarine slides on the continental margin. A likely mechanism for initiation of submarine sliding involves a breakdown of hydrates at the base of the hydrate layer. The effect would be a change from a semi-cemented zone to one that is gas-charged and has little strength, thus facilitating sliding. The cause of the breakdown might be a change in pressure on the hydrates due to a sea-level change, such as occurred at the start and end of glacial periods when ocean water became isolated on land in great ice sheets or liberated with their ablation. Understanding hydrate-sediment stability is also important for other uses of the seafloor, such as waste disposal and submarine communication cables.

Within the Irish sector, research into the theoretical extent of former gas hydrates (during glacial times) has been modelled by the Renard Centre of Marine Geology, University of Gent, Belgium under the auspices of Prof. Jean-Pierre Henriet. These models suggest former
hydrate accumulation in water depths shallower than 900m that may explain slope instabilities and carbonate mound formation (Henriet et al., 1998).

4.2.2 Synthesis of current extent and recoverability of methane hydrates in Irish waters

4.2.2.1 Potential distribution of gas hydrates in Irish waters

Areas where gas hydrates may potentially exist in Irish waters are presented in Figure 4.4 based on theoretical hydrate stability fields. Basal water temperatures off southwest Ireland are c.14°C and decrease moving northward. On this basis it is suggested that the hydrate stability field may exist at water depths in excess of 1100m (Peter Croker, DOMNR, personal communication; Jean-Piere Henriet, University of Gent, personal communication). At 2000m water depth, it is possible that BSRs could occur at depths of 500m below the seabed surface. However, it should be stressed that although hydrates may be present in this area, there is no available evidence of any BSRs having been found in Irish waters to date.

Despite the current lack of evidence for the existence of hydrates in Irish waters, it is not reasonable to regard this as a conclusive position. It has been pointed out (Michael Max; personal communication, see Appendix XII) that evidence of hydrates in seismic records may not be recovered through standard interpretative procedures to which the records would normally be subject for petroleum exploration purposes. In addition, it has been stated that hydrate mapping requires target specific and specialised integrated survey techniques focused at shallower depths than for conventional hydrocarbons (Miles & Max, 1999). Also, the conditions under which the records were collected can often impact on the detectability of hydrates. It is further suggested that the presence of hydrates may help to account for extensive evidence of submarine slides on the edges of the Rockall Trough.
Figure 4.4 The area in which hydrates may theoretically be found in Irish waters based on phase stability with respect to ambient temperatures and pressures, i.e. where water depth exceeds 1100m.
4.2.2.2 Prospects of economic recovery of hydrates from Irish waters

The prospects for recovery of hydrates from Irish waters within the foreseeable future appear slim for the following reasons:

- The economic and political imperatives driving progress in other countries are of less importance in the Irish context.
- No evidence of hydrates has yet been found in Irish waters despite reasonably detailed seismic profiling.
- If hydrates do exist then they are likely to be in concentrations that are too low to make them competitive with other accumulations globally and therefore are unlikely to ever become viable.
- Hydrates would occur as buried deposits (if present). Those deposits that will be extracted first internationally are likely to be from accumulations that spill onto the surface of the seabed. These conditions occur in extremely deep water at low latitudes, with depth of occurrence reducing with increasing latitude, thus favouring the possibility of viable production in arctic and sub-arctic regions.
- The hydrate stability zone in Irish waters occurs below 1100m where accumulations in other areas of the world occur at shallower depths and are therefore likely to be exploitable earlier.
- The technology for extracting hydrates from the seabed is not currently available on a commercial basis, although there are speculative suggestions that Japanese technology may be close to making this possible.

4.2.3 RTDI initiatives

A vast amount of research is needed to understand the behaviour of hydrates; their role in slope processes, their role in climate regulation, to develop better surveying and quantification technology and to develop technology for extraction. The US, Japan, India, Canada, England, Brazil, Norway, and Russia are currently undertaking this work. However, the rationales and imperatives that underpin research being undertaken by these nations is not shared in the Irish situation. Appendix IX contains the executive summary of the US Dept of Energy National methane hydrate multi-year R&D program plan. The full text of this document (see list of URL's) contains a very comprehensive and detailed breakdown of research themes and topics that are related to pertinent US national policy issues, at least some aspects of which may offer potential for Irish participation in the future.

4.2.3.1 Hydrate research in Irish waters

As far as can be ascertained there is currently no research specifically dedicated to naturally occurring hydrates being conducted in Ireland. Given the minimal prospects for viable extraction in Irish waters, there seems little incentive for international players to participate directly in collaborative projects. Without outside expertise and the specialised advanced deepwater seismic reconnaissance equipment that would currently be required, there appears little prospect for the development of useful programs of research in Irish waters based on the resource per se. However, there remains the possibility that future seismic exploration, re-interpretation of existing records or other research may uncover further evidence of diffuse hydrate structures. The role played by gas hydrates in the geological past with respect to slope mass-wasting events and other instability features, does offer some research potential. These themes link with interests in the hydrocarbons sector with respect to geo-hazards to man-made offshore structures. Some of these issues have been the subject of
recently completed programs e.g. ENAM I & II, from which further hydrate-related research has arisen e.g. COSTA

The role of methane in carbon budgets as a greenhouse gas and thus its impact on past present and future global climate models has been flagged as an area of important research (US Dept of Energy, 1999; see Appendix XI). Global climate studies can be linked with existing and forthcoming research in Irish institutions (Ignacio Lozano, CRC personal communication) and can therefore be considered of indirect relevance to Irish interests.

4.2.3.2 Hydrates in pipelines

Spontaneous hydrate formation is a phenomenon that is known to occur in offshore gas pipelines, necessitating adequate engineering provision for avoidance of potentially catastrophic blockages. There may therefore be potential to further develop existing Irish engineering and process modelling expertise to address these issues with relevance to Irish hydrocarbon interests. Collaborative opportunities may follow to generate research and technology that, whilst addressing hydrate formation as a problematic feature, could lead to improved understanding of "natural" hydrate behaviour as a spin-off. These aspects are discussed in the hydrocarbons section (2.3) in relation to the high potential for gas being landed from the Corrib field. The GSI have suggested that there is a need to quantify the extent and nature of gas hydrates in Irish waters as they represent a significant geohazard with respect to submarine cable laying (M. Geogheghan, GSI, personal communication).

4.2.3.3 Examples of international Hydrate research

(a) Case study of Idaho National Engineering and Environmental Laboratory

The following information is drawn from the INEEL (Idaho National Engineering and Environmental Laboratory) website. This text illustrates how particular research themes are targeted within US gas hydrate research strategy as a whole. Points that are considered to be of relevance to potential (future) Irish RTDI prospects are marked with an asterisk.*

Understanding Methane Gas Hydrate Potential and Hazards*

Methane gas hydrates are a remarkable natural phenomenon that may represent a significant fuel source. They may also constitute an important environmental hazard because their release could contribute to global warming. Either way, researchers need to understand the distribution and quantities present in subsurface environments. Methane gas hydrates have been found in deep marine or sub-permafrost sediments along continental margins and along the Arctic Ocean. However current methods of detection may not locate all deposits.

The INEEL Solution: Improve Hydrate Detection Methods*

Researchers at the Idaho National Engineering and Environmental Laboratory are studying the basic microbial and chemical processes that form hydrates, and the range of formations, to develop better methods to find and quantify them.*

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1 (EU-FP5 funded program, contact: Prof. Juergen Mienert Dept of Geology University of Tromso, Dramsvein 201, N-9037, Tromso, Norway. Tel +47 77644446. Juergen.mienert@ibg.vit.no)
The Research: Collect, Study and Grow Hydrate-loving Microbes

To do this, distribution of microbial communities in vertical sections of the hydrate-rich sediments is studied to understand where microbes live, and where they don’t live, and to characterise the relationship between the location of the microbes and the location of the hydrate. In some areas, microbes coexist with high concentrations of methane, which is not what the researchers expected. Researchers assumed that the microbes’ growth would be limited in high concentrations of methane, the product that they manufacture as a waste. INEEL researchers also grow microbes in hydrates in laboratory bioreactors to study how they survive and produce methane in controlled conditions, and if the hydrates confer any advantage to microbial growth. In the process, they are applying new tools to determine the cell activities of the methane-producing bacteria, especially in sub-permafrost and marine sediments that have little biomass. Researchers are also extracting DNA to obtain signatures of the different types of methanogens present in deep sediments. To date, the researchers have grown marine methanogens at pressures consistent with hydrate zone pressures and found that pressure alone does not prevent methane production. Above hydrate zone pressures, however, a loss of activity is seen. Researchers have collected and analysed the microbes from sediments off the coast of Japan, and from the Mackenzie Delta in Canada’s Northwest Territories. Investigations are focusing on why such high numbers of methanogens have been found, which can be grown in the laboratory, in sandy zones, but fewer numbers in clay zones. Currently, researchers are designing an experiment in which they plan to grow mixed or pure cultures of methanogens in a bioreactor, with and without methane hydrate. Two molecular-based assays are also being developed for use with these samples, as well as a method to use PCR to amplify the DNA of methanogens present in marine sediments so that they can be identified without growing lab cultures.

The Future: Map Fuel and Hazard Sources of Hydrates

The work being done by the INEEL researchers is discovery science. By understanding more about the microbes that produce methane, where they exist, and their levels of activity, researchers will be able to map the distribution of methane hydrates and possibly estimate the rates of methane production. This research will help identify the best sources of fuel, as well as the areas that may be prone to catastrophic release of methane gas.

(b) Novel hydrate research, special applications in clathrate technology.

A number of new and interesting research topics are associated with methane hydrates. Although peripheral to the main resource oriented thrust of this report, some have been included as they are deemed to have intrinsic merit and could be of interest to Irish researchers in a wider context of marine technology based RTDI. Max, Pallanbarg & Hurdle (1997) give detailed descriptions of the themes outlined below.

De-Salination

A novel area of research associated with methane hydrates is exploring the potential in desalination of seawater. The concept is based on a long pipe-like structure placed in the ocean into which methane is introduced at the bottom. Hydrates form, and rise to the top (water surface) liberating the gas for recycling and leaving behind fresh water which pools at the top and can be piped off. Much research is needed to perfect this technique but given the future for fresh water as the next world commodity, there would seem to be plenty of incentive.
Marine construction material
Gas hydrates have been suggested as a replacement for traditional cement/aggregate based concretes for deep-marine engineering applications where high strength is not specified. There are many advantages of this approach including the fact that only gas would be required at the site, as seawater and local aggregate could be used as the remaining ingredients. Additionally, reformation or removal would be relatively simple by melting with the application of a low grade local heat source. Suggested applications include fixing pipelines or cable in position, securing well-head completions to aid blow out protection, and construction of undersea habitats.

In-situ energy
This concept uses the pressure differential between gas trapped below a hydrate layer and the seabed surface. The pressure differential can be harnessed to drive simple turbines. However a great many technical issues need to be faced with respect to realising this potential. If successful the concept could lead in the long term to a considerable gain in recoverable energy based not just on gas recovered from (in particular) small shallow deposits, but from turbines placed in the pipelines supplying gas to the grid.

Industrial feedstock
Methane is a primary source of fixed carbon, which can easily be converted into a range of valuable higher molecular weight materials, including fuels (methanol), and structural polymers. The idea here is that the processing hydrates and associated methane could be accomplished in-situ, and thus take advantage of ambient pressures.

Synthetic Methane Clathrate Fuel Media (SMCF)
By modifying the gases mixed into clathrate during formation it is possible to arrive at a substance which has high energy density and is stable at ambient pressures and temperatures unlike the naturally occurring material. Although the energy density of SMCF is substantially less than that of conventional liquid fuels (e.g. petrol) it is likely to be high enough to be used in situations such as ships. Additional uses are anticipated as a safer fuel storage and transportation medium, where the solid phase offers numerous advantages over traditionally uses of gas in a liquefied form. In common with all of the above concepts, there are an enormous number of technical and engineering obstacles to be overcome, but stimulus is provided by universal drive towards cleaner, greener, and more versatile fuel sources.
4.2.3.3 Summary of Hydrate related RTDI issues in the Irish context

The main hydrate research topics are seafloor stability, climate change, energy, and special-focus topics such as sonar response effects and local biological impact.

- Hydrates as a component of the geomorphological system, rather than their role as a future economic resource, are the focus of current research initiatives in Irish waters. This will likely remain the case in the absence of specific initiatives to broaden the research agenda.
- Existing (reviewed) seismic data, and best available theoretical considerations indicate a low probability for the existence of commercially viable gas hydrates deposits in Irish waters. The presence of some hydrates cannot however be entirely ruled out, as evidence in extant seismic records may have been overlooked.
- Enhanced technologies currently under development internationally can usefully be observed and kept under review for potential application in Irish waters, particularly with respect to anticipated improvements in detection methods.
- Extractive technology is still not mature, although there is a very large potential for development in this area that may be open to Irish researchers through international collaborative arrangement even in the absence of a domestic resource.
- Most current international research is very costly and driven by (speculative) national strategic policies that are themselves driven by demand through lack of alternative energy supplies.
- Some niche areas of research associated with aspects of hydrate physical and chemical properties, as well as biochemical associations, may offer potential for involvement of Irish researchers.
- The balance of evidence suggests that the development of viable gas hydrate extractive industry is highly unlikely in Ireland in the near to medium term (0-10 yrs), although application of technologies under development abroad may facilitate access in the longer term.
- Highly specialised expertise in the field world-wide is currently confined to a small number of key individuals. In Ireland, the current knowledge base and levels of interest in hydrates are rudimentary. A detailed theme focused review of all information pertinent to gas hydrate occurrence and survey is suggested to help delineate areas of highest potential based on known theoretical indicators. Close liaison with PAD may be required for these aspects. Formation of a strategy for investigating the long-term potential for hydrates in Irish waters may be facilitated through holding a conference and workshops that would serve to pool available international evidence and discovery expertise. There would appear to be an opportunity for the MI to adopt a pro-active and co-ordinating role with respect to many aspects of research associated with hydrates.
4.3 Carbonate Mounds

4.3.1 Current international experience with respect to the exploration and development of carbonate mound resources

4.3.1.1 Formation and occurrence of carbonate mounds

Carbonate mounds are prominent reef-types present during earth history since Cambrian times, frequently forming giant host rocks for hydrocarbon accumulation. Their formation and environmental controls have been discussed in contradicting ways. Our present day knowledge of reef growth and reef formation is limited to the shallow water coral reef environments of the tropical regions and to a few observations of reefs from the cool water coral margin off Europe. Understanding of modern deep-water carbonate mounds is very incomplete.

Although the recovery of coral fragments has been recorded from trawl records since the middle of the 19th century, carbonate mound structures were first formally recognised and described scientifically in early part of the last decade, as anomalies on commercially produced seismic charts by Dr. Peter Croker of Ireland’s Petroleum Affairs Division (Hovland, Croker & Martin, 1994). At this time, parallels were drawn with similar structures recorded from further north on the continental margins in Norwegian waters, and from Australian waters. It was not until 1997 however when these anomalies were mapped in detail by the University of Gent researcher Prof. J.P. Henriet on board the Belgium vessel Belgica that the dome-like structure of these features was fully realised. Subsequent cruises by the Russian vessel Logachev and the Netherlands vessel Pelagia have further extended the range of these carbonate mounds over a wide area off the west coast of Ireland.

Carbonate mounds are particularly well developed in Irish waters offering some of the world’s most spectacular examples, and are thus a focus for international research with respect to mound exploration. This means that to a great extent current international experience coincides with Irish national experience.

Examples with cross sections between 100-1800m at their base, rising up to 350m above the seabed and surrounded by a 60-90m deep circular moat, have been reported in the Porcupine Seabight in water depths of 650-1000m. Three distinct areas of mound growth have been identified in the Porcupine Seabight: Hovland Mounds, northern Porcupine, Magellan Mounds, buried mounds in the northern Porcupine and Belgica Mounds in the eastern Porcupine. More recently, carbonate mounds up to 350m high were discovered on the continental slope north of the Porcupine Bank in water depths of 500-1100m. In addition, carbonate mounds have been described in a zone up to 9 miles wide in water-depths of 500-1000m in the south western Rockall Trough. These mounds also rise up to 350m above the seabed and appear associated with slumped or faulted margin sediments.

How these mounds were formed is still a question. The theory put forward by the Belgian researchers is that seepage of methane gas from the seabed provided a food source for bacteria that in turn provided food for coral forming species (Henriet et al., 1998). Over millennia, huge mounds of coral and carbonate mud built up. Current theories postulate that there must be other mechanisms involved in maintaining the integrity and shape of the mound structure and thus new research teams (see below) including marine microbiologists will look at the possibility of the slopes of the mounds being stabilised by bacterial slimes.
Furthermore, these vast biogenic accumulations may offer clues as to the role of microbial mediation in bio-mineralisation and calcification in particular.

Based on data generated by high resolution seismic profiling and a few sidescan sonar records, the mounds of both the Porcupine Seabight and Rockall Trough appear to extend parallel to the slope, at the present boundary level between Eastern North Atlantic Water (ENAW) and Mediterranean Outflow Water (MOW). This discovery may suggest that the mounds owe their existence more to enhanced nutrient flux as opposed to hydrocarbon seepage. Initial studies of the $\delta^{18}O$ and $\delta^{13}C$ isotopic composition of skeletal material of mound biota showed a clear marine signature controlled by ocean circulation. Differences of the $\delta^{18}O$ signal within individual species have been related to variations in growth rate and are thought to reflect variability in food supply during skeleton growth and possibly of ambient seawater temperature. So far, the limited data set on isotopic signals from the Norwegian, Faeroes and Porcupine Seabight mounds failed to show any controls other than those of water masses (De Mol et al., 1998).

These biogenic accumulations are for the most part located within the depth range of the habitable zone of corals and apparently support a rich deep-water reef ecosystem. The acceptance of a simple model of mound formation is unsatisfactory due to the observed variation in size, morphology (linear ridges, ring shapes etc.) and the prolific number of these mounds with their very localised clustering. An explanation for their yet poorly documented and regionally studied distribution, shape, composition and formation in relation to the seismic and sedimentary characteristics of the margin and a relationship to the local extant oceanographic conditions is not as yet available. During the past 5 years observations have been published and there are presently two, so far unproven hypotheses regarding their origin. One hypothesis (Hovland et al., 1994, and 1998) relates the development of mounds to leakage of hydrocarbons or methane seepage by fluid flow from below, whereas the other hypothesis suggests external, environmental related forcing in combination with geological setting for the development of the mounds (Wheeler, et al., 2000).

As the mound provinces are occurring at or near areas of increased exploration for hydrocarbons, there is an obvious need to better understand their occurrence and origin and to establish their potential impact on seabed stability and their relationship to external forcing mechanisms.

Deep coring on and around the mounds has been extremely limited so far, although many superficial cores have been collected. In the Porcupine Seabight and Rockall margin, the mounds seem to be composed of (carbonate) debris, from the breakdown of abundant ahermatypic Lophelia and Madrepora cold-water corals and associated fauna, hemipelagic sedimentation, and coral frameworks. Piston-core sampling of mounds in Porcupine Seabight and the SE and SW Rockall Trough margins showed the surface sediments to be built up at intermittent intervals with carbonate debris, including the cold-water corals Lophelia pertusa and Madrepora oculata, and shell fragments, separated by clayey layers. This indicates spatially intermittent or heterogenous mound growth, related to increased carbonate sedimentation, separated by periods of quieter sedimentation, involving mound formation by a combination of pelagic and detrital sedimentation.

Preliminary studies on organic matter show low total organic matter in both the Porcupine Seabight and SE Rockall Trough mound sediments, with an isotopic signature reflecting a
mixture of terrestrial and marine sources. Biomarker studies of a SE Rockall Trough mound showed a distribution of fatty acids and n-alkanes suggesting a considerable land-derived contribution of terrigenous lipids, in addition to plankton-derived material.

The EU 5th framework has funded 3 major international projects addressing various RTDI questions with respect to carbonate mounds on the European margin. These projects run for 3 years and started in April 2000. The objectives of these projects are set out below:

4.3.1.2 International research initiatives

(a) Ecomound

Irish partners in ECOMOUND include:

Coastal Resources Centre, UCC (Dr. Andy Wheeler, & Mr Max Kozachenko)
Martin Ryan Institute, NUIG (Dr. John Patching & Dr. Martin White)

The major objective of this proposal is to define the environmental controls and processes involved in the development and distribution of carbonate mounds on the NW European continental margin. The project will establish the relationship between carbonate mound biota and recent water-mass characteristics and dynamics, as well as with sedimentological properties of the surrounding seabed. Based on growth rates of mound biota, a high-resolution record of recent short-term watermass composition and variability will be obtained based on stable isotope analyses of "well-dated" benthic carbonate skeletons. This will allow a better understanding of the effects of environmental forcing factors and their variability. The final aim is to differentiate between carbonate mounds and mud mounds and to determine whether they are indicators for hydrocarbon resources.

Finally these vast biogenic accumulations may offer clues as to the role of microbial mediation in bio-mineralisation and calcification in particular. The recent discovery of a rich deep biosphere in association with methane hydrate horizons, deeply buried under the seabed, in various oceans, suggests similarly that biogenic mounds with likely methane-associated bacteria may herald opportunities for tapping into new microbiological resources (enzymes) for Europe's biotechnological industry.

ECOMOUND envisages 6-7 cruises to obtain high resolution spatial information in four key areas along the NW European margin. These areas are presently being explored for hydrocarbon resources. The four areas are the Porcupine Seabight and the Rockall Bank (in Irish waters), the northern Rockall Trough (in British waters), and the Sula Ridge areas (in Norwegian waters).

A wide range of equipment will be deployed at selected sites, including landers (deep-sea observatories), sonar systems, high-resolution single and multi-channel seismic systems, cameras, sediment traps and corers. Biologists, microbiologists, geochemists and sedimentologists will form a team to identify clues of mound-forming processes related to oceanographic and environmental boundary conditions. The observations and analytical results will be used to formulate and drive a model. The model will test various hypotheses concerning how environmental processes control the presence and distribution of carbonate mounds.
The objectives of ECOMOUND are set out below:

- Aside from new area-related knowledge concerning the distribution, size, shape of mounds and their relation to sedimentary settings and water mass conditions, an overall synthesis will be made of the environmental controls governing mound formation and biological distributions on the European Margin.

- The direct coupling of hydrographic, geological and geochemical data sets on the scale of this study will yield new insights in the dynamic effects and processes involved in particle transport, settling and re-suspension governing mound growth along the margins of NW Europe.

- The role of mound biota in the sequestration and biotransformation of organic matter and the sources and composition of organic matter involved in mound development will be evaluated in contrasting mound areas. Microbially mediated processes contributing to mound formation will be identified.

- A largely unknown habitat will be explored which comprises an essential part of the European Margin.

- Temporal and spatial variability of carbonate production and lithogenesis in and around mounds will be defined and its relationship to environmental forcing established.

(b) ACES – Atlantic Coral Ecosystem Study

Irish partners in ACES include:

Coastal Resources Centre, UCC (Dr. Andy Wheeler & Max Kozachenko)
Martin Ryan Institute, NUIG (Dr. Anthony Grehan & Dr. Martin White)
EcoServe (Dr. Mark Costello)

The aim of the ACES project is to produce a margin-wide environmental baseline assessment of the status of Europe's deep-water coral margin with recommendations for essential monitoring and methodology requirements for future sustainable development. The evolution of new management concepts for a sustainable use of deeper water marine ecosystems over a margin-wide scale is a grand challenge that can only be achieved on a joint European scale (Annex V of the OSPAR Convention). The overall objectives of ACES are as set out below:

- Map the structural and genetic variability, the framework-constructing potential, and the longevity of deep-water coral (DWC) ecosystems over the latitudinal gradient of the European NE-Atlantic.

- Assess hydrographic and other local physical forcing factors affecting benthic boundary layer particle dynamics and particulate organic carbon supply.

- Describe biodiversity, dynamics and functioning of the DWC ecosystem; coral biology, behaviour and sensitivity to both natural and anthropogenic stress.

- Designate an ecosystem sensitivity coding, highlight major conservation issues, and make practical recommendations for the sustainable use of the DWC ecosystem.
The following tasks are being carried out as part of this program:

- the generation of high frequency side-scan sonographs
- the generation of video structural maps
- elucidate reef forming potential proxies
- study coral genetics
- determine local physical forcing factors
- quantify the contribution of particular organic carbon
- perform visual faunal identifications
- perform faunal sampling and identification
- perform fish censuses and assess spatial distributions
- determine ecosystem food webs
- study coral reproduction
- perform recruitment experiments
- make in situ behavioural observations
- study coral habitat dominance
- study coral biodegradation

(c) Geomound

Irish partners in GEOMOUND include:

Dr. Pat Shannon (University College Dublin)
Dr. Peter Croker (Petroleum Affairs Division, Dept. of Marine & Natural Resources)

The intriguing coincidence of large provinces of giant carbonate mounds with actively explored hydrocarbon basins on Europe's Atlantic margins and their frequent association with surface expressions of fluid flow has provided the impetus for a detailed investigation of their significance for the evaluation of fluid-related slope hazards. A large-scale geophysical and geochemical investigation project is underway, in close partnership with industry, to support an integrated fluid migration modelling exercise. The model will encompass the whole migration pathway in mound environments, from reservoir to shallow subsurface. Scientific drilling proposals will be prepared, both through (I)ODP and a possible European action with a drilling vessel as Research Infrastructure, as well as a Marie Curie Industry-Host Fellowship proposal for training purposes.

The discovery of most prolific carbonate mound provinces along Europe's margins, coincidental with the present deep-water areas of interest for hydrocarbon exploration, provides the impetus for investigating the potential links between giant mound occurrences and hydrocarbons resources. Considering the close association between mounds and various surface expressions of fluid expulsion, "mound events" may hold clues towards fluid migration phases and hence prospectivity of basins. The apparent association between various mound clusters and past events of slope failures suggests mounds may also hold a key towards slope stability assessment. Finally, the high-resolution investigations proposed will also help to unveil and document the unique deep water coral ecosystems often associated with such mounds, to contribute in this way to Europe's efforts to develop its natural resources with due consideration for the preservation of such deep water habitats.

The areas to be studied by GEOMOUND include the following (see figure 4.5):

- a buried carbonate mound in the western most part of the Magellan mound province
an extant mound in the Belgica mound province
a mound on the north-west flank of the Porcupine Bank
a mound in the Hovland mound province
an area of fluid escape in the Connemara oil field in the Rockall margin.

GEOMOUND ultimately hopes to develop a coherent fluid migration model, supported by high-resolution field data sets, as a tool for the interpretation of mound occurrences in hydrocarbon fields and for the management of European margins. The generation of an (I)ODP proposal and its possible twinning with a European drilling vessel action can be a pilot for post-2000 multi-platform drilling.

Beyond the possible importance of such mounds as potential carriers of messages from Europe's deep hydrocarbon reservoirs, including pulsation, dynamics of fluid migration and expulsion in recent geological times, this project may result in the unveiling of one of the planet's most fascinating meeting sites between biosphere and geosphere. It has been proposed that giant carbonate mounds with their apparently thriving ecosystems might be for the margins what large sulphide mounds and their fascinating hydrothermal ecosystems are to mid-ocean ridges. The mound ecosystems need to be studied, with a view to selective conservation where appropriate.

(d) Associated studies

All the above projects will strongly interact, and develop ad hoc co-operative links with DEEP-BUG, COSTA and STRATAGEM. Such co-operation may form the ground for relevant clustering initiatives, in harmony with the EU strategy. Proposals have also been accepted for a French-funded submersible dive program on the Porcupine Seabight and Rockall margin (CARACOLE). In addition to the three 5th Framework programmes that have all now progressed positively through an initial cycle of fieldwork, other smaller studies have been initiated and are as follows:

- CARACOLE. Investigations of carbonate mounds and cold coral in the Porcupine and Rockall Basins. International project for access to the IFREMER Victor ROV to be deployed from the RV Atalantile for biological and geological investigations. Irish proposers: Dr. Anthony Grehan, Dr. Andy Wheeler & Dr. Pat Shannon. Proposal accepted and project to be carried out between July 29-Aug 15, 2001.

- ODP proposal submitted to drill to the base of a carbonate mounds.

- Application for access to the TOBI\(^1\) and BRIDGET\(^2\) seafloor survey facilities, for a survey in the Porcupine Seabight and Rockall Trough over carbonate mounds: Irish proposer: Dr. Andy Wheeler. This project has been accepted for part funding which will cover all costs except ship time, funding for which is currently being sought.

- Belgian national research programme repeated visits to the Belgica Mound to perform high resolution seismics. Leader Jean Pierre Henriet.

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\(^1\) Towed Ocean Bottom Instrument Deep-towed 30kHz sidescan sonar system developed and operated by Southampton Oceanography Centre (SOC).

\(^2\) A deep-towed instrument designed specifically for the detection and mapping of the buoyant plumes of hydrothermal vents (SOC).
Repeat Dutch national survey program linked to studying carbonate mounds in Rockall Trough- leader Tjeerd van Weering.

4.3.2. Synthesis of current extent and recoverability of coral mounds in Irish waters

These corals are present throughout the world at appropriate water depths. What is also evident is a concentration of deep-water coral sightings in European waters. Although this may in part be due to a denser network of surveys in these waters, the proliferation does in part seem to reflect a real increase in population density. This notwithstanding, in Irish waters, deep-water corals are associated with spectacular carbonate mounds of global significance. Thus the abundant occurrences in Irish waters provide a true focus for global deep-water coral research.

Figure 4.5 shows the distribution of carbonate mounds in Irish waters as documented by PAD. Possible additions to this distribution have recently been mapped during the GSI seabed survey. The map identifies 4 main provinces of extant mounds as well as a province of buried mounds in the northern Porcupine Seabight (Magellan mounds). All of the mounds occur at intermediate water depths on the continental margin or northern Porcupine Seabight. All of the extant mounds are accessible with conventional deep-water vessels and technologies that are widely available to European research institutes or survey companies. However, it needs to be pointed out that this infrastructure does not exist in Ireland at present. The national research vessel *Celtic Voyager* is capable of operating in these areas in fair weather but is a small platform lacking suitable gear and winches to operate equipment required for surveying and cannot guarantee a stay on site for the necessary period of time required to do effective work. This shortfall is soon to be addressed through the acquisition of a new, larger national research vessel. Nevertheless, deep-water video systems, sampling gear and acoustic survey equipment will have to be acquired to allow an effective study of Ireland’s deep-water geo- and biosphere resources. Currently this equipment must usually be hired from outside of Ireland at (high) commercial rates.

Buried mounds exist at depths of 10’s to 100’s of metres below the seabed and present considerable surveying difficulties. Although it is possible to image them with high-resolution seismic equipment, obtaining any physical product requires deep drilling. This is only possible through collaboration with the hydrocarbon industry operating in Irish waters or through international ocean drilling programmes. Steep financial considerations may prohibit the recoverability of any buried resource. Although Ireland is currently limited in the hardware required to fully utilise and evaluate this resource, there are no other practical hindrances to RTDI initiatives.
Figure 4.5 Distribution of Coral mounds in Irish waters (data source PAD, plotted by CRC)
4.3.3. RTDI initiatives

4.3.3.1 Introduction

Any RTDI initiative instigated with respect to carbonate mounds in Irish waters needs to be mindful of the significant body of EU-funded research that has recently commenced. This research addresses most, if not all, of the fundamental questions relating to carbonate mounds. The research packages are multi-disciplinary targeting and integrating relevant themes in the biosphere, geosphere and hydrosphere. The programmes draw on considerable international marine infrastructural resources including appropriate scientific vessels (with deep coring capabilities), state-of-the-art surveying equipment (very high resolution side-scan, seismics and digital video equipment), international scientists with expertise in deep-water coral environments and links with other potential international programmes (e.g. drilling programmes, industrial links, French national submersible dive programmes, etc.).

In this context, it could be argued that any strategic RTDI initiatives put forward by Irish authorities should wait until these programmes are advanced. This would allow time for some of the fundamental questions relating to carbonate mounds to be answered and, as is often the way with research, point the way to further questions and issues that need to be addressed.

Nevertheless, these major research initiatives, although biased towards Irish waters (as they contain the most spectacular examples of carbonate mounds known in the world), are not exclusively directed to addressing Irish carbonate mound RTDI issues. The projects aim to address a European-wide agenda. In this context, there is scope considering themes that are closely linked to the existing programmes but place heavier emphasis on the national agenda. Furthermore, the EU projects are only a necessary first step. Irish national research programs should be strongly aligned with the European studies to gain maximum scientific benefit. Never before has there existed such an opportunity to capitalise on international interest in cooperation and assistance for Irish deep-sea research.

4.3.3.2 Potential carbonate mound related project themes

A series of potential project themes are described in this section and presented with an accompanying scientific rationale.

Mapping all of the mounds in Irish waters both in terms of their specific locations, morphological variability (hence elucidating controls), construction and composition

Existing research programmes cover both detailed site-specific studies (intensive multi-disciplinary studies of individual mounds) and spatial studies (addressing morphological variation and controls between mound provinces). In this context, there is a potential for a fuller inventory of carbonate mound characteristics covering all mounds in Irish waters which will not be studied during the present funding round. Analysis of the spatial pattern of the mounds can give information of possible localised generation mechanisms, such as fluid seeps along deeper seated faults (which would cause the mounds to occur along lines associated with these faults, Hovland et al., 1994). Geostatistical analysis of estimated mound sizes and other properties could reveal possible trends e.g. indicating a decaying support mechanism in certain directions. Besides previously unmapped mounds, other relevant seabed anomalies are also present relating to, for example, gas seeps or slope
failures. Pockmarks have been reported in the area (Wheeler et al., 1998b), and their location with respect to the mounds can give important clues in understanding possible links.

**Carbonate mounds and related margin processes**
Slope failures such as slumps, debris flows and turbidites within canyon systems are common processes along the North Atlantic continental margins (Kenyon, 1987). One of the obvious examples in the Porcupine Seabight is the Gollum channel system (although largely a relic feature [Tudhope & Scoffin, 1995; Wheeler et al., 1998a]). Slumps may have also been present in the Belgica province and escarpments appear present in the Hovland province and the Rockall Trough site (Nielsen et al., 1998). On the 3D seismic block of the Magellan province, a clear slump can be seen, located more or less under the buried mounds raising the question as to what extent slope processes are linked to mound growth and occurrence. The role of gas hydrates in slope instabilities (Henriet & Mienert, 1998) and link between gas release and mound genesis is tantalising.

**A large-scale TOBI and BRIDGET survey**
This would allow mapping all the features indicating hydrocarbon seepage, and help in establishing the spatial correlation with mound occurrence. The use of BRIDGET would assist in the quantification of hydrocarbon seepage, and facilitate a comprehensive investigation of the linkage between contemporary gas escape and mound genesis. Pockmarks have been described in the Porcupine Seabight (Wheeler et al., 1998b) and clear indications for fluid escape were found in 3-D seismic data in the northern Porcupine (Connemara Field). A link between the deeper (commercial) hydrocarbon reservoirs and seafloor processes is therefore apparent. However, few similar structures were mapped in relation to the mound provinces.

**An assessment of the role that carbonate mounds play with respect to fish nurseries**
Because these carbonate mounds represent vibrant centres of biological productivity at intermediate water-depths, it has been suggested that they may represent important nursery grounds for intermediate to deep-water fish. The current government initiative on deep-water fisheries research could benefit from an assessment of the role that carbonate mounds play with respect to fish nurseries. Not only would this help in understanding the behaviour of little-known deep-water fisheries and assist in effective sustainable management of this resource, but it may also enable a qualified assessment of the need to protect carbonate mounds from destructive practices in order to boost the potential deep-water fisheries industry.

**Effects of current fishing practices in the vicinity of carbonate mounds**
There is evidence to suggest that the greatest current threat to carbonate mound habitats may come from trawling. Concentrations of fish are often found in waters above the mounds availing of the increased food supply associated with the high biological productivity occurring below. Trawling of these fish shoals can occasionally result in accidental damage to the benthic communities on the mounds (especially the coral) if the trawl is set too deep. Recent SOC video imagery has revealed snarled nets on one of the mounds in the Porcupine Seabight. Furthermore, it has been the practice of some fishermen (not necessarily in Irish waters) to flatten the surfaces of the mounds (causing total destruction of the coral as well as damage to other communities). These destroyed mounds then attract abundant short-lived fisheries after a few days due to the activity of scavengers. There is a clear need to address the effects of current fishing practices in the vicinity of the mounds to provide better
sustainable management of this resource to the benefit of all interests especially the fishermen.

**Assessment of role and potential of carbonate mound associated chemosynthetic bacteria**
The discovery of new vibrant ecosystems opens the way to discovery of new biocompounds of use to the pharmaceutical and biotechnology industries. Recently, these industries have expressed an interest in the little understood communities of the deep ocean, particularly the chemosynthetic bacterial communities of hydrothermal vents and gas hydrates. Given the richness of carbonate mound ecosystems and the strong role played by bacterial communities in mound formation, RTDI potential exists in studying these bacterial communities for potential industrial spin-offs.

**Investigation and development of high resolution climatic signals from carbonate mounds and investigation of the impacts upon and relationships with existing climatic models**
Due to the fast growth rate of carbonate mounds, it has been speculated that a high resolution climate record can be extracted from carbonate mounds comparable to that of ice-core data. A clarification of this potential (although not the record) may be elucidated from the current EU-funded programmes. Considering the maritime control on Ireland’s climate, there is potential for further research in developing a high resolution climatic signal from carbonate mounds that would be of direct relevance to the modelling of the Irish climate and therefore enabling better forecasting of climatic changes with respect to the greenhouse scenario. This initiative would provide an indirect investment for Ireland through enhanced predicative capacities and as well as driving international research in this field.

**Suite of studies of current flow and other oceanographic parameters through a program of extensive field measurements and refinement of existing flow and oceanographic models**
Identification of internal wave effects, and elucidation of relationships with mound growth and formation.
- Integration of acoustic records and current flow measurements leading to improved understanding of sediment dynamics in vicinity of mounds
- Seasonal and other controls on the relative position of principal water masses in relation to mound location and genesis

The current EU-funded projects address the potential role of currents as controls on mound growth largely (although not exclusively) using models. Mindful of the need to generate a comprehension of water column current variations on Ireland’s continental margins for engineering requirements associated with the hydrocarbon industry and fisheries, the deployment of current meters over mounds may not only assist in an appraisal of the role of slope currents on mound growth but also provide data for other initiatives. Currents are not only able to shape mound morphologies but also to affect their sedimentary environments. Drift sequences are seen on high-resolution 2D seismics indicating sediment deposition both in Porcupine and Rockall that are sometimes associated with cut and fill structures indicating dynamic current regimes in the area. On the present-day seafloor, bedforms are found comprising sandwaves, striations and sand patches (Kenyon, 1986; Wheeler et al., 1998b) that indicate the presence of the general northward ‘slope current’ in the Belgica province and Rockall Trough. However, superimposed on this general system, internal waves may also exist (Pingree & Le Cann, 1989; Rice et al., 1991) especially in the Belgica province. TTR7 side-scan sonar fragments revealed much rougher image textures for the background
sediments in the Belgica province (Huvenne, 1999), indicating a more intense current regime compared to the Hovland province. Studies to identify zones of internal wave effects, and their relation with mound position and mound growth are needed. Integration of these results with water properties would help to understand the sediment dynamics of the areas. Chemical characterisation of the water could indicate areas of sediment reworking and resuspension and allowing nepheloid layers to be tracked (as found by Dickson & McCave (1986) on the Porcupine Bank).

Furthermore, currents are extremely important for *Lophelia sp.* (e.g. Frederiksen *et al.*, 1992; Freiwald *et al.*, 1997). Current information inferred from side-scan sonar images and measurements made by the ADCP would be of extreme value for the biological & ecological study of the mound phenomena.

Besides current regimes, the water signatures (chemical composition, temperature, nutrient content, suspended matter, etc.) are of great importance to the cold-water coral associations (Freiwald *et al.*, 1997). As mound provinces are located in the boundary layer between the Mediterranean Outflow Water (MOW) and a deeper water mass with the influence of Labrador Sea Water (Rice *et al.*, 1991), both water masses may influence their ecosystems. An exact positioning of these water bodies and an estimation of the gradients of water properties over the boundary layer seems necessary in the understanding of the cold water coral ecology.

The input and exact pathway of the MOW in the Porcupine and Rockall is an important issue in physical oceanography (New *et al.*, in press), any information on the position and characteristics of this water mass would be of extreme value. The analysis of the physiochemical properties measured by BRIDGET would also increase the understanding of the influence of internal waves, as they are strongly affected by density gradients in the water.

4.3.3.3 Outlook for carbonate mound linked research: summary of limitations and opportunities

The extent of international expertise being brought to bare on Irish carbonate mound research highlights the inability of the Irish research community to appraise Ireland’s deep-water resources due to limitations in available infrastructure. To a certain extent this may be alleviated by the provision of a new deep-water research vessel although the acquisition and/or development of deep-water survey equipment for the national equipment pool is needed. There is a growing perception among Irish deep marine specialists that the level of funding being provided by the MI in support of international collaborative research proposals may not be sufficient to ensure their realisation. Examples of projects in this category include the TOBI/BRIDGET survey, CARACOLE, and elements of the UCG HEA bid. Carbonate mounds offer a spectacular showcase to the development of new deep-water technologies where rigorous testing can occur and impressive, aesthetic, eye-catching images can be obtained to facilitate better marketing and stimulate further investment. Suitable and needed technologies, which would facilitate exploration of deep-water carbonate mound resources, include digital video and camera systems, high resolution deep-tow seismic and side-scan sonar systems, AUVs, as well as coring and sampling equipment.
4.4 Heavy Mineral Sands

4.4.1 Current international experience with respect to the exploration and development of heavy mineral sand resources

4.4.1.1 Characteristics and formation of placer deposits

Marine placer mineral deposits are found on continental shelves world-wide, and these resources can exist from the beach to the outer shelf. Valuable commodities including gold, diamonds, platinum, tin, chromite, iron-sand, zircon, ilmenite, rutile and monazite have all been mined commercially from such deposits.

A placer deposit is an accumulation of mineral grains concentrated by sedimentary processes. Placers are formed through the sorting action of waves or water flow, which tend to concentrate minerals of higher specific gravity (3.0 to 5.0 g/cu cm) and resistance to weathering. Marine placers form in exposed, shoreline or nearshore environments in areas of active winnowing by waves or long-shore currents. They occur along present day beaches, and are also preserved as relict deposits or raised strandlines that formed during glacially induced low or high sea level stands. Beach placers accumulate mainly in the upper foreshore and backshore depositional environments. Geological settings include sand spits, barrier islands, coastal dunes, buried marine scarps, drowned fluvial deposits and submerged residual or lag deposits overlying bedrock or till. The concentration of minerals in deposits is dependent on the following factors: source rock, weathering, transportation and trapping by sub-aerial processes and subsequent reworking and modification by marine processes. Varying littoral drift rates and directions, altering wave energy distributions, and changing water levels contribute to local and regional variations in placer distributions. Conditions in sheltered embayments appear to favour the concentration of fine-grained metalliferous sediments where they are supplied by feed rivers, and concentrated by current eddy conditions.

4.4.1.2 World distribution of placers

Heavy mineral sands have been extracted from marine placers throughout the world, the main locations are indicated in Figure 4.6.

Figure 4.6 World distribution of placer heavy mineral sand deposits
4.4.1.3 Mineral types and principal mining operations

Diamond

Diamond mining in offshore Africa began in 1961 and has become a major contributor to the world diamond market. Several companies, including the diamond giant De Beers, are operating offshore both Namibia and South Africa with very large dredges and at-sea processing plants. Diamonds are now dredged in water as deep as 180 meters and remotely operated bulldozers with large suction hoses connected to a processing ship have been tested for mining in even deeper water. Diamond mining off Namibia's Skeleton Coast is a billion-dollar industry in itself. More than 650,000 carats valued at over $180 per carat were taken from the Namibian mines in 1996. Most of these marine diamonds have travelled thousands of miles from inland sources and have been subjected to intensive wave action, resulting in very high quality gemstones. The South African diamond mines are some of the most profitable and sophisticated offshore mining operations in the world, with start-up costs for a marine operation running at $80 million, which is a quarter of the cost of a typical new land venture.

Gold and platinum

Gold and Platinum as noble metals yield very high returns and can be mined from beaches and nearshore areas off Alaska, British Columbia, Nova Scotia, Phillipines and Russia. Between 1986 and 1990 the WestGold Corporation recovered gold in state waters off Nome, Alaska, using the Bima a converted Indonesian tin mining dredge. Estimated reserves exceed $500 billion, however, despite relatively rich deposits the operation was closed mainly due to steadily declining gold prices. There are currently no mining operations for platinum although Alaskan operations have been successful in the past and good prospects remain. The US consumes about one-third of the world's total annual platinum mine production, and its probable consumption is projected to increase by 63 percent from 1983 to the year 2000 so there should be an interest in the offshore potential. A continuing vulnerability of the US's platinum supply, and an anticipated growth in demand for the metal, make it important that a greater effort be made to locate and develop domestic sources.

Titanium

The strategic element titanium, derived mainly from ilmenite and rutile ores, is an important placer mineral. About 5 percent of the world's annual production are consumed in making metal alloys that need special strength and corrosion resistance. Titanium placers occur in the US (see Figure 4.7), West Africa, along the coast of Mauritania, and on the continent's opposite coast, near the south eastern shore of Madagascar. The titanium mining industry, in the past, experienced "boom and bust" periods. Its fortunes are tied to the amount of activity in the military and commercial aircraft industries. With future growth likely in the worldwide aerospace industry, titanium will continue to play an important role in world markets. Total titanium metal consumption is expected to increase annually in the U.S. by 5.5 percent between 1983 and 2000; the probable annual rate for the rest of the world will be 26.2 percent.
Tin

The best known and most important marine metallic placer is tin which is found in the mineral cassiterite. The world's most important area for offshore tin production is in waters surrounding the Malay Peninsula and those lying between Sumatra and Kalimantan. About 7% of the global production of tin is mined offshore Malaysia, the world's most important tin producer, had 31 percent of its total tin output come from the offshore in 1984. The offshore now accounts for 50 percent of Thailand's total annual tin production. The Indonesian Government expected to produce nearly half the country's annual total output of 27,000 tons in 1986 from the offshore, and currently a fleet of over 30 bucket-line dredges are working off Indonesia, processing over 40 million cubic meters a year of sediments to recover tin ore. Offshore or beach tin placers also occur in the UK, USSR, US (Alaska) Burma, the Peoples Republic of China, and the Philippines.

The world market for offshore production of tin is estimated to be from $1-2 million to $100 million, but the industry has been in a deep depression. The U.S. alone has potential tin placers off the coast of Alaska worth approximately $39 billion dollars, which are not being mined presently. The surplus problem is made worse because not all tin-producing states are members of the trade cartel. Bolivia and Brazil, the world's fourth and fifth largest market-economy producers continue to produce without quotas. The tin market is in oversupply, and the outlook for offshore tin mining in the near future is grim. The tin industry should recover, although many of the less efficient producers may have been eliminated.
4.4.2 Synthesis of the current extent and recoverability of heavy mineral sands in Irish waters

Known chiefly from beaches since the last century, heavy mineral sands have been noted from several locations around the Irish coast. The examination of one deposit on Achill Island in the 1970's led to a GSI reconnaissance survey of metamorphic and igneous coastlines and the subsequent recognition of several new locations. Interest from the exploration industry followed in the 1980's, and several companies carried out evaluative work at that time. The main areas of interest were NW Donegal, Mayo, and south of Wicklow head on the east coast (see Figure 4.8).

Fig 4.8. Locations of heavy mineral sand prospects (after Geoghegan et al., 1988, and Sutton and Wheeler 1998)
4.4.2.1 Mineral sands in Co Mayo.

The beaches of Blacksod Bay were found by GSI reconnaissance survey to be rich in heavy minerals including ilmenite, magnetite, sphene and some gold. It was also suggested that cassiterite and minerals for the columbite-tantalite series might be present on the west side of Blacksod Bay, having been derived from the stanniferous Annagh gneisses. A prospecting license was applied for and geophysical and sampling work covering an extensive area in the bay was carried out by Burmin Exploration and Development plc., in conjunction with the GSI. Some detailed results of this survey (sample locations and sediment thickness) are available from the GSI and are also presented in the MRM Sand and Gravel data base (Sutton & Wheeler, 1999). In summary, an area of 30km$^2$ was identified as containing sand with heavy mineral showings. Detailed mineralogy results are not readily available for samples acquired during this work; those available are on-site descriptions giving presence or absence of minerals. Records indicate (Geoghegan, 1988) that further investigative work using viborcoring was planned for Blacksod Bay, but was apparently not carried out.

4.4.2.2 Mineral sands in Co.Wicklow.

Beach sands south of Wicklow Head at Brittas Bay have also been the objects of commercial interest in the late 1980s, and an extraction license was applied for by Avoca Gold Exploration plc. The source of the heavy minerals in this area is thought to be erosion of terrestrial Ordovician metasediments and other volcanic rocks in the region. Samples of material resulting from a trench-sampling program were analysed by Leeds mining consultants. The mineralogy of these samples is presented in Table 4.1. The non-magnetic heavy minerals are of most interest, with garnets and ilmenite providing the greatest contributions. Important economic components include: rutile, magnetite, monazite, chromite with zircon, sphene, epidote, chlorite and staurolite. Avoca Gold Exploration plc have estimated 30,000 tonnes of concentrate to be present in beach sands (above HW) of Brittas Bay and some smaller beaches to the north, which would apparently have been commercially viable for extraction. No extractive activity has been recorded to date however, and despite a plan for mitigative seasonal extraction procedures, future developments are unlikely in view of the high amenity value of the area, and concerns over coastal erosion. Although there are placer deposits of gold in the vicinity of this area, only trace amounts have been recorded from beach sands.
Table 4.1 Mineral sand compositions from samples taken at Brittas Bay, Wicklow (after Geoghegan et al., 1988)

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<th>Other Fe minerals</th>
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Analysis of Sinks Fractions (based on total weight of beach sand samples)

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<td>4</td>
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<td>1</td>
<td>56</td>
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<td>9</td>
<td>47</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>43</td>
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<td>3</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>1</td>
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<td>2</td>
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<td>6</td>
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</tr>
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<td>12</td>
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<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>2</td>
<td>6</td>
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<td>2</td>
<td>1</td>
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<tr>
<td>13</td>
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<td>14</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>69</td>
<td>3</td>
<td>14</td>
<td>22</td>
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<td>57</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>51</td>
<td>1</td>
<td>5</td>
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<td>4</td>
<td>4</td>
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<td>1</td>
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<td>0.5</td>
<td>52</td>
<td>0</td>
<td>4</td>
<td>13</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
Since the GSI/commercial studies, the authors have not been able to discover any specific research work that has been undertaken in direct connection with the further development of Irish heavy mineral sand prospects. Some recent research work has been considering ways to trace the provenance of sediments in the eastern Irish Sea through precise analyses of their mineralogical constituents in relation to that of source rocks on land (John Malone, 1998; personal communication). The final outcome of this work is not known at the present time.

Although the primary source of interest in mineral sands may reside in the commercial value of their mineralogical components, physically they comprise part of the coastal sedimentary system. Thus their removal or disturbance will have similar impacts in common with other granular sediments. There are various initiatives to gain a fuller understanding of the complex interactions between beach sand volumes and the conformation of offshore banks and channels. This work is set to continue, although it is primarily led by concerns over the pace of coastal erosion, the effects of which are manifest at many locations on the east coast. Refer to section 3 (sand and gravel) for further discussion on these aspects.

4.4.3 RTDI initiatives associated with placer mineral deposits

International research is predominantly focused on the following main issues:

- Improvements in resource prospecting; discovery, mapping, quantification and characterisation
  - Improvements in recovery techniques and technology
  - Mitigation of environmental effects

Some examples of promising techniques with potential for application in Ireland are presented in detail below:

4.4.3.1 Induced Polarisation (IP)

Arising from the need to improve resolution in reconnaissance techniques particularly in shallow sediments, the USGS has been conducting experimental evaluations of induced-polarisation techniques, formerly successfully used in terrestrial prospecting applications. The induced-polarisation (IP) method works on land by injecting current into the ground by means of an array of electrodes, then detecting a secondary voltage signal from additional special nonpolarizing electrodes after the inducing voltage is temporarily turned off. This method has been used on land for nearly half a century to search for disseminated (very low grade) sulphide ore deposits. It works by causing ions in the ground water to migrate under a high voltage onto minute mineral surfaces. When the inducing electrical field is removed or temporarily turned off, the finite "bleed-off" time for these charges to move back to the ground water can be measured as a phase shift (or time lag between the inducing transmitted voltage and the measured receiver voltage). This finite bleed-off, or time shift between the induced and the measured voltages, is the IP effect; it is commonly expressed as milliradians or fractions of a transmission cycle. An IP effect in field measurements indicates that there are sulphide minerals or certain other minerals such as ilmenite or clays in the ground between the high-voltage transmitter and the receiver (detector) arrays.

The IP method can detect pyrite (iron sulphide) in minute quantities, sometimes as low as 0.1-0.2 percent. In the early 1970s, a variant of this IP method called "complex resistivity" or "spectral IP" was developed. Instead of measuring just one or two physical parameters
(for example, resistivity and phase shift) at a single frequency, this approach measures both resistivity and phase shift (also sometimes called the "chargeability") over a wide range of frequencies. With this wide spectral range, the behaviour of the IP effect can be plotted (the complex resistivity) on a graph of magnitude vs. phase resulting in distinct "signatures" for different mineral assemblages. Until the mid-1980s, however, the IP method had never been tried at sea because of the high conductivity of seawater and engineering difficulties in controlling noise in the signal.

Laboratory and field experiments by the U.S. Geological Survey (USGS) in the early 1980's (Wynn et al., 1990) showed that the IP method on land was extremely sensitive to certain titanium-bearing and thorium-bearing industrial minerals such as ilmenite and monazite, respectively. These measured IP responses were unprecedented in their unusual strength. The earlier land-based effort invited experiments with the IP method in the offshore environment. The USGS constructed a prototype marine IP streamer (consisting of 13-conductor cable with IP transmitter and receiver electrodes, and pre-amplifiers). This rig (Figure 4.9) was towed behind a ship off the Georgia coast and gave very promising results (Wynn, 1988). On land, electrodes must be dug or pounded into the ground to make IP measurements; at sea, one uses stainless steel or titanium wire wrapped around the streamer, and seawater conductivity makes the return path for the transmitted current. This use of seawater instead of planted electrodes has the serendipitous effect of making IP work highly mobile.

![Figure 4.9 A schematic diagram of the marine induced-polarization (IP) streamer being towed. Note that there are two different receiver electrode pairs (1-3 and 2-4). Pair 1-3 is designed for shallow (up to 6 feet or 2 meters) detection, and pair 2-4 is for deeper (up to 20 feet or 6 meters) depths into the underlying sediments.](image-url)
These prototype experiments demonstrated that marine IP is a practical approach for mapping heavy minerals (including ilmenite) in the shallow offshore environment. Experiments with the spectral IP technique (where the IP effect is measured as both magnitude and phase shifts over a frequency range of 0.1-100 hertz) gave ambiguous results. This was because spectral IP measurements can be made only by using a stationary streamer. Because of limitations with the navigation equipment available at the time (LORAN), difficulties were encountered in precisely reoccupying locations of some mineral-loaded vibrocores, or even to reoccupy with sufficient precision some towed-mode IP "hits." Examples of ilmenite-bearing deposits mapped nearby onshore are usually highly localised, typically being 20 meters wide by 500 meters long.

Following the initial success with the prototype streamer, a new USGS project was established to further extend and experiment with innovative applications using this promising technique. The Offshore Industrial Minerals Project is a multidisciplinary effort intended to involve a wide range of partners both inside and outside the USGS in mineral and hazards research in the shallow offshore environment. Project goals include development of a geophysical and geologic toolkit for identifying and quantifying industrial mineral concentrations, waste dumping materials, construction aggregate, beach-reclamation resources, and beach-reclamation sediments on the shallow offshore continental shelves of the United States. The primary tool for this project, as outlined above, is a USGS-developed marine induced-polarisation technology. The USGS initially developed this new electrical streamer system to directly detect placer heavy minerals, certain clays, and disseminated metals directly on the sea floor from a moving vessel. The USGS realise that it also can
provide porosity information about layered sediments. During their surveys, they also acquire precise GPS (Global Positioning System) location information and integrate the two. Subsequent evolutions of the IP streamer system will also incorporate bathymetry.

Additional tools that may be used include the following:

- Petrographic microscopes and an electron microprobe: these will be used in conjunction with laboratory electrical measurements to precisely characterise the cause of the unusually strong IP effect in some placer minerals.
- Magnetic separators and heavy-media separation chemistry.
- Specialised geophysical contouring and plotting software.
- Neural network technology to undertake real-time analysis of field data on-board ship.

This class of investigatory systems would appear to offer potential for application and possibly additional further development in the Irish context. Such systems if proven effective may become attractive to international prospectors on the world market.

Despite failing to make mineral sands commercially viable in Ireland in the 1980’s, the initial results were favourable and a re-evaluation of the situation may now be warranted. Principal objections lay with environmental concerns: disturbance of in-fauna and the threat of accelerating coastal erosion. The unfavourably suppressed price of metal on the world market also contributed to the failure of the venture to become commercial.

Technological advances in underwater heavy mineral detection methods could facilitate a better quantification of Ireland's heavy mineral resource (See also section 3.5.5.2 CRISP). This may provide an impetus to stimulate further economic evaluations. Investigations into the effects of extraction on biological communities would also seem warranted given the nature of concerns governing former activities.

The complicated nature of near-shore sediment transport in the southern Irish Sea requires investigation not just to understand the effects of mineral extraction on near-shore sediment budgets but also to understand the offshore components of coastal erosion and the dynamics of offshore banks and structures. An investigation of this type would assist in the utilisation of mineral sands in the Irish Sea as well as assisting other questions of national interest.
4.5 Metalliferous Nodules and Crusts

4.5.1 Current international experience with respect to the exploration and development of metalliferous nodule and crust resources

4.5.1.1 Characteristics and formation of metalliferous deposits

Two main classes and several subclasses of metalliferous minerals are recognised within this deep-sea resource category:

1. Metalliferous Oxides (low-temperature formative processes):
These are of economic importance owing principally to their cobalt content, but they also contain significant quantities of manganese, copper, and nickel. They occur as two distinct sub-classes with distinct morphology and formation:

Manganese, or polymetallic nodules. These occur as loose or lightly embedded ovoid or globous nodules on seabed sediment or among rock debris at oceanic depths (c.5000m) mostly commonly in equatorial Pacific.

Cobalt-rich crusts. These are thin (2.0cm) deposits that encrust exposed rock substrates between 800-2400m water depth, usually on the flanks of seamounts, ridges and volcanic islands.

2. Polymetallic Sulphides (high-temperature formative processes):
This class of mineral deposits is of economic significance owing mainly to the presence of high (and extremely variable) percentages of iron, zinc, copper and lead, although many other precious metals have also been recorded. They are associated with volcanically active areas, and are mainly found on mid-ocean ridge spreading centres, and in island arc systems (black smokers). Although both arise from mineral precipitation out of superheated mineralised seawater, two distinct morphological types can be described as follows:

Solid chimney or vent structures. These are generally discrete, usually hard and resistant structures formed of metal sulphides (also includes some oxides and silicates) deposited in successive layers so as to form a distinct tube. They may reach several metres in length.

Extensive deposits. The other main form in which metal sulphides occur is as extensive (tens of kilometres in length) often deep (20-30m) mounded deposits, comprised of the coalesced remains of fallen chimneys. Precipitation beneath the sea surface augments these processes forming "stockworks" within the oceanic crust.

4.5.1.2 Polymetallic nodules

The first sub-marine ferromanganese concretions were discovered in 1868 in the Kara Sea (Russia). Many small dark-brown balls, rich in manganese and iron, were collected during the H.M.S. Challenger expedition (1873 to 1876). Formally named as manganese nodules, international interest in their resource potential was sparked at that time. Around 1900, the scientist Agassiz found nodules in many sampling programs made in the Eastern Pacific ocean. Nodules were also collected in cores and dredges by the scientific expeditions that surveyed the global ocean. It was only after 1957 that John Mero succeeded in convincing...
some industrialists of the economic potential of nodules and led them to explore the Central Pacific Ocean (Mero, 1966). In the early 1960s, manganese nodules started to be considered as potential resources for nickel, copper, cobalt and even manganese, as competition was high for supplies at that time. This provided the incentive for multimillion-dollar investment by mining companies in mining and processing technology. The first commercial interests to be involved were Kennecott and Newport Shipbuilding Company who began sampling cruises in 1962. Concomitantly, US scientific investigators (Fuerstenau & Arrhenius) were studying nodule geochemistry and metallurgical processing. From 1965, new companies undertook important research in nodule exploration, mining and processing, notably AFERNOD (France). In 1972, the US National Science Foundation launched a research program that employed at least fifteen scientific laboratories in the study of nodule genesis. In the Soviet Union, Bezrukov published a voluminous book on Pacific nodules. Large scale industrial exploration expanded appreciably only after 1982.

Description and formative origins of polymetallic nodules
Manganese nodules are regarded as ores for nickel (Ni), copper (Cu), and cobalt (Co), with the best varieties known to occur in the north eastern tropical Pacific and central Indian Ocean. They obtain their metal content through complex processes that are not yet fully understood. Nodules appear in the form of small black-brown slightly flattened boulders with a diameter of between 5 and 10cms, and they are normally found in water depths of between 4000m and 6000m. The density of nodules is 2g/cm$^3$, with typical water content of 30%, and porosity of 50%. Theories for nodule genesis include both mineral and biological concepts. The principal formative processes associated with the mineral theory are as follows:

"hydrogenous": a slow precipitation of metallic components from the seawater, that forms concretions having similar iron and manganese content, and are relatively high in (Ni+Cu+Co).

"hydrothermal": producing concretions that are generally rich in iron, but poor in (Ni+Cu+Co).

"diagenetic": giving rise to nodules that are rich in manganese and poor in iron and (Ni+Cu+Co), through manganese remobilisation in the water column and precipitation at the sediment-water interface.

"halmyrootic": where the source of metallic components is the seawater weathering of basaltic debris.

Theories favouring biological mediation are supported by the observation that nickel and copper enrichment in south equatorial Pacific nodules appears to be related to organic fluxing of metals under the high biological productivity equatorial zone. Highest nickel and copper contents occur in the depth range of the calcium carbonate compensation depth, which occurs between 4900m and 5300m in this area. Outside this depth range copper and nickel content decrease. The following factors also have to be considered in relation to nodule formation:

- A low rate of sedimentation, which leaves concretions the opportunity to grow before being buried away from conditions favourable to their development.
- Metallic hydroxides of biological origin contain copper and nickel that can be incorporated to ferromanganese concretions.

- Manganese in seawater seems to come from the leaching of the basalts and essentially from hydrothermal activity along medio-oceanic ridges.

- Microbial activity appears to enhance the process of concretion formation.

The size and shape of nodules are highly variable (roughly spherical, more or less ovoid), and they are classified according to three main forms:

- **mononodule**: simple nodule, spherical or ellipsoidal
- **polynodule**: a nodule with several cores,
- **composite nodule**: several joined nodules

In section, most nodules show concentric layers (cortex) that correspond to the successive phases of growth around a core, which is often microscopic. The core may be a fragment of an old nodule, a shark tooth or a rock fragment (basalt, limestone, etc). The layers are formed of hydroxides of manganese (Mn) and iron (Fe), which are found in varying degrees of crystallisation. The more crystallised they are (todorokite, birnessite), the richer in Mn, Ni and Cu, while cryptocrystallised structures (vernadite) are richer in Fe and Co. Several studies have shown that Ni and Cu are either adsorbed in the ferro-manganese hydroxides, or incorporated in their lattice, filling the Mn$^{2+}$ sites of todorokite or birnessite. The more crystallised the nodules, the higher their metal grades. However, valuable-element recovery (Ni, Cu) seems to be easier when crystallisation is incomplete.

In general the growth rate of nodules is extremely low (in the order of 1cm per several millions years). The age of Pacific Ocean nodules is 2 to 3 millions of years. However faster forming ferromanganese incrustations have been also observed near ships wrecked during the First World War, or around motor plugs. This seems to indicate that a metal source other than seawater is necessary. If nodules are formed slowly, "hydrogenous" or "diagenetic" processes can be considered, however for quick forming nodules, "hydrothermal" or even "halmyrolitic" processes can be envisaged. Figure 5.1 shows a cross-section through a typical monodule.

**Figure 5.1 Cross section through a typical manganese nodule**
The following facies descriptions are based on results of extensive exploration work carried out by French vessels as part of the AFERNOD program in the Pacific. Examination of seabed photographs obtained by ED 1 (autonomous freefall benthic sampling and photographic device) highlighted the existence of morphologically different facies within areas containing nodules. Comparative photographic and chemical analyses highlighted the relationships between nodule and facies morphology, and chemical composition. Three main families are recognised, and classified in accordance with the following criteria.

- Distribution of nodules on the seabed
- Estimated mean diameter
- Sediment-nodule relationships
- Presence or absence of barren areas

**Facies A:** Composed of 70-80% small nodules with complex irregular forms. Often includes (0-30%) of nodule debris. Nodules stand proud of the sediment, are often accompanied by rock debris of volcanic origin, and are frequently associated with rock outcrops. Ferromanganese hydroxides are not well crystallised, and have a confused or laminate structure.

**Facies B:** Most nodules are ovoid and often occur among the debris of ancient nodules. Their surface is smooth in texture, sometimes having small rounded lumps. They are distributed evenly on the bottom. The hydroxides are not well crystallised, having a laminated or badly organised structure.

**Facies C:** These are by the largest nodules, and have a conspicuous equatorial rim. They are found buried in sediment up to this line, and are often recovered from a bed of soft sediment that partly masks their appearance. They are homogeneously distributed on the seabed. Hydroxides are well crystallised but still exhibit similar laminar characteristics as A & B. The boundary between areas of facies B and facies C is not clearly defined, and occurs as a progressive transition.

<table>
<thead>
<tr>
<th>Facies</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (b)* (mm)</td>
<td>20-30</td>
<td>30-70</td>
<td>50-100</td>
</tr>
<tr>
<td>Roundness (b/a)*</td>
<td>Complex forms</td>
<td>0.74</td>
<td>0.69</td>
</tr>
<tr>
<td>Flattening (c/b)*</td>
<td>0.64</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Population (%)</td>
<td>28</td>
<td>31</td>
<td>13</td>
</tr>
<tr>
<td>Abundance (kg/m^2)</td>
<td>5.2</td>
<td>11.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Mn (%)</td>
<td>19-26</td>
<td>28-31</td>
<td>25.4-31.2</td>
</tr>
<tr>
<td>Fe (%)</td>
<td>6-10</td>
<td>5.5-6.5</td>
<td>4.6-6.8</td>
</tr>
<tr>
<td>Ni (%)</td>
<td>0.5-0.9</td>
<td>1.15-1.3</td>
<td>1.05-1.25</td>
</tr>
<tr>
<td>Cu (%)</td>
<td>0.25-0.35</td>
<td>0.26</td>
<td>0.23</td>
</tr>
<tr>
<td>Co (%)</td>
<td>0.25-0.35</td>
<td>0.26</td>
<td>0.23</td>
</tr>
<tr>
<td>SiO₂</td>
<td>12-23</td>
<td>12-17</td>
<td>12-14</td>
</tr>
</tbody>
</table>

* With a > b > c: the three axes of nodules, best represented by a flattened spheroid.
World nodule distributions and mining Interests

Figure 5.1a World distribution of nodule occurrence (1969).

Figure 5.1b. Areas where nodule concentrations are highest

From the distribution maps shown above (source IFREMER), it can clearly be seen that although nodules and metallic encrustations are found world-wide, areas of high (economic) concentration are relatively restricted. In 1973, Horn demonstrated the predominance of the east-west belt of the southern part of the northern Pacific, between the Clarion and Clipperton fracture zones, known afterward as the "Horn zone". It was in this area that most mining companies had by that time, begun programs of exploration. Although no commercially viable development of the metals-rich manganese nodule deposits has occurred to date, official mining exploration licenses have been held since 1984 by several multinational companies in an area of the Pacific Ocean between Hawaii and Central America. There has also been recent interest by Japanese and Chinese firms in manganese nodules off the Cook Islands and other areas in the Pacific. Table 4.3 gives a summary of the main consortia that have held, or are holding exploratory mining concessions.
### Table 4.3 Summary of the main consortia that have held, or are holding exploratory mining concessions

<table>
<thead>
<tr>
<th>Name</th>
<th>Key Dates</th>
<th>Notes on concessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean Mining Associates (OMA)</td>
<td>Oct 1974</td>
<td>No data</td>
</tr>
<tr>
<td>Kennecot Consortium (KCON)</td>
<td>1974-1993</td>
<td>No data (company dissolved 1993)</td>
</tr>
<tr>
<td>Ocean Management Inc (OMI)</td>
<td>1975</td>
<td>No data</td>
</tr>
<tr>
<td>Ocean Minerals company (OMCO)</td>
<td>1977</td>
<td>Took up KCON zone (1993)</td>
</tr>
<tr>
<td>Deep Ocean Resources Development Company (DORD)-Japan</td>
<td>1987</td>
<td>Zone of activity of 75,000-km² - North Pacific.</td>
</tr>
<tr>
<td>Technology Research Association of Manganese Nodules Mining System (TRA) - Japan.</td>
<td>1987</td>
<td>Under the MITI charged with development of a nodule collection system</td>
</tr>
<tr>
<td>Yujmorgeologiya (Former Soviet Union)</td>
<td>1987</td>
<td>Zone of activity of 75,000-km² - North Pacific.</td>
</tr>
<tr>
<td>Department of Ocean Development (DOD) India</td>
<td>1987</td>
<td>150000 km² in the Indian Ocean</td>
</tr>
<tr>
<td>ARERNOD-France</td>
<td>1987</td>
<td>75,000 km² in the north Pacific Ocean</td>
</tr>
<tr>
<td>Interocean Metal</td>
<td>1992</td>
<td>150000 km² in the in eastern part of the Clarion-Clipperton zone of the north Pacific</td>
</tr>
<tr>
<td>COMRA-China</td>
<td>1992</td>
<td>150000 km² in the in western part of the Clarion-Clipperton zone of the north Pacific</td>
</tr>
<tr>
<td>KADOM- Korea</td>
<td>1994</td>
<td>150000 km² in the in central part of the Clarion-Clipperton zone of the north Pacific</td>
</tr>
</tbody>
</table>

Japan has also maintained a consistent interest in deepwater economic minerals, and the main elements of research undertaken in co-operation with the South Pacific Applied Geoscience Commission (SOPAC), are detailed below.

**Japan/SOPAC deep-sea mineral resources survey program**

This program started in 1985 as a five-year co-operative study project between Japan and SOPAC. The purpose of this program was to assess the potential of deep seabed mineral resources, such as manganese nodules, cobalt-rich manganese crusts and hydrothermal deposits within the (EEZ) of SOPAC member countries. The Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ) under the supervision of the Japanese government have executed this project.

**Phase 1: from 1985 to 1989 was as follows:**
- 1985 Cook Islands - North Penrhyn Basin for Manganese Nodules
- 1986 Cook Islands - South Penrhyn Basin for Manganese Nodules
- 1987 Kiribati - Phoenix Islands for Manganese Nodules & Cobalt-rich Crusts
- 1988 Tuvalu - Ellice Islands and Ellice Basin for Manganese Nodules & Cobalt-rich Crusts
- 1989 Kiribati - Southern Line Islands for Manganese Nodules & Cobalt-rich Crusts

The Total survey area was 1,852,000km²

**Phase-II that started in 1990 and concluded in March 1995 is as follows:**
- 1990 Western Samoa - Samoan Islands for Manganese Nodules and Cobalt-rich Crusts
- Cook Islands - Southern Cook Islands for Manganese Nodules
1991 Kiribati - Gilbert Islands Group for Manganese Nodules and Cobalt-rich Crusts
1992 Papua New Guinea - Manus Basin for Hydrothermal Deposits
1993 Solomon Islands & Papua New Guinea (partial) - Woodlark Basin for Hydrothermal Deposits
1994 Vanuatu - Coriolis Trough for Hydrothermal Deposits

The total survey area was 2,664,200 km²

Phase-III: Following on from the valuable results of both Phases I and II, and the keen interest and support shown by the Federated State of Micronesia, Fiji, Marshall Islands and Tonga to have their waters included in the survey program, the Japanese Government approved the extension of this program for a further five years, bringing to 15 the total number of years of continuous research in the area.

Phase-III started in 1995 was planned as follows:
1995 Tonga - Tonga Ridge and East Lau Basin for Hydrothermal Deposits and Cobalt-rich Crusts
1996 Marshall Islands - Whole Area (East) for Manganese Nodules and Cobalt-rich Crusts
1997 Federated States of Micronesia - Northern West Area for Manganese Nodules & Cobalt-rich Crusts
1998 Federated States of Micronesia - Northern East Area and Marshall Islands - Whole Area (West) for Manganese Nodules and Cobalt-rich Crusts
1999 Fiji - North Fiji Basin and West Lau Basin for Hydrothermal Deposits

The results of projects over the past ten years have been incorporated into the "South Pacific Seafloor Atlas", the first of its kind for the south Pacific covering Phase-I and Phase-II namely Cook Islands, Kiribati, Tuvalu, Western Samoa, Papua New Guinea, Solomon Islands and Vanuatu.

Economic deposits
The best Ni and Co rich varieties of nodules have to date mostly been found to occur in the north eastern tropical Pacific, and central Indian Ocean (Non-EEZ waters). Enrichment appears to be related to overlying high biological activity. Deposits that have more recently been found within the waters of south equatorial Pacific Island nations are of lower nodule abundance (low metal concentration per unit seafloor). Important nodule concentrations do, however, occur within some national EEZ areas such as the Cook and Phoenix Islands, Republic of Kiribati. These occur in abundance of greater than 30kg/m² containing more than 0.6% cobalt. This abundance, and high cobalt content has been explained in terms of their occurrence under areas of Antarctic bottom water flow, which reduces sedimentation and enhances nodule abundance. Slow growth rates may be linked to cobalt enrichment (Cronan, 1990). Results of resource assessments in some of the Commonwealth CCOP/SOPAC nations of the south Pacific indicate that 100 million tonnes of nickel equivalent metal quantity (Ni+Cu+Co) exists in nodules where they occur in densities of greater that 5kg/m² (possible economic cut-off limit). The Phoenix Islands have resources of approximately 12 million tonnes of nickel equivalent metal quantity.

Exploitation rights and sovereignty
Metalliferous nodules and crusts are considered together as an EEZ resource, although most of the most abundant sites are not within national EZ limits, and are thus now subject to international jurisdiction under UNCLOS International Sea Area designation for areas outside 200 mile limits. The current situation regarding terms of allocation of exploration...
permits has arisen throughout a period when international agreements relating to seabed exploitation were heavily contended. This complex evolutionary process eventually took account of the pioneer investors who had begun a program of broad reconnaissance in the Pacific during the early 1970's. Licensing agreements now take into account issues such as technology transfer and profit sharing mostly between developed and developing nations. These matters have since 1996 been administered by the International Seabed Authority, which is based in Kingston, Jamaica. Further detailed information can be obtained from the Seabed Authorities website that is listed in the URL section at the rear of this document.

**Current and future commercial potential**

IFREMER (France) has had a strong research program Association Française pour l'Etude et la Recherche des nodules (AFERNOD) which has concentrated on many aspects of the commercial exploitation of manganese nodules. The bulk of this work was carried out in five phases between 1970 and 1987 in the Pacific. Originally covering an area of 2.5 million km$^2$, the area of research was refined to cover an economic area of few tens of thousands of km sq. This very extensive program of deep marine RTDI is comprehensively documented on the IREMER website. Some of the main findings and conclusions of this research are presented below:

A deeper understanding of the characteristic constraints and knowledge gaps will have to be obtained in order to be able to take decisions in relation to the exploitation phase. During the course of the research program, AFERNOD was able to develop new types of equipment (e.g. ED$^1$, l'Epaulard$^2$, le RAIE$^3$, le SAR$^4$, all used for resource quantification and to resolve microtopography) with improved efficiency, and which will have important spin-offs for other areas of deep-water exploration;

Knowledge acquired through the exploration phase enabled GEMONOD (part of the AFERNOD program) to determine a harvest area, and a preliminary assessment of the economic feasibility of nodule exploitation. The number of sites to be mined during the first exploitation phase will be dependent on the following factors:

- The intended annual extracted tonnage;
- The minimum duration of extraction;
- The efficiency of collection systems;
- The quality of material retained.

Preliminary economic feasibility studies indicate that to be commercially viable, an annual level of production in excess of 1.5 million tonnes of dry nodules (containing nickel, copper, manganese and cobalt) per annum would be required. This corresponds approximately to the production of one collection unit. The equipment that is required for exploitation of nodules has a life expectancy of 20-25 years. Harvesting efficiency is very hard to estimate, on account of a wide range of conflicting opinion among experts in the field.

Considerations on production levels and the potential for losses of material in the course of production between collection and delivery at the treatment plant, mean that nodules must be collected at the rate of 117kg/s at the intake nozzle. This translates to sweeping a corridor of 15m in width from a bottom deposit concentration of 14.4 kg/m$^2$ with a loss of 17% at a speed of 0.65 m/s.

---

1 Autonomous mechanical low cost benthic photographic apparatus and sampler.
2 Autonomous submersible for deepwater photographic acquisition.
3 Deep towed instrument platform for collection of continuous photographic and bathymetric data.
4 Side-scan sonar.
The realisation of a pilot, pre-industrial, nodule collection project would provide an important focus for the development of interesting offshore and deep marine technology. International developments in deep marine technology annually reduce the level of difficulty of achieving successful harvesting of nodules. Thus the technical problems are likely to be overcome. The profitability of such an undertaking then evidently depends on the international industrial context.

The metallurgical treatments that were studied were based on the techniques for processing uranium and nickel, and were very successful. Two forms of treatment were retained, hydrometallurgical and pyrometallurgical. Both methods produced a mean recovery of more than 90%. Although there was no technical advantage with one over the other, the hydrometallurgical technique offered a better return on investment in the start-up phase.

Under economic perspectives pertaining at the time of this research (1987), it was envisaged that harvesting could be profitable by the beginning of the 21st century. This was based on the theory that the richest available sources of nickel would have been exhausted leading to the stabilisation of its price at a sufficiently high level to permit extraction from nodules. In the interim it is likely that new exploration and production techniques will appear.

Another aspect central to the viability of future economic nodule recovery is the need for a prospective extractor to be able to secure an exclusive concession of sufficient duration to a specific site. As far as the current authors have been able to determine, the world price for nickel has not yet stabilised at a level that would render manganese nodule extraction viable. World metal markets are currently depressed, and world supply capacity for cobalt currently exceeds demand.

4.5.1.3 Metalliferous crusts

Crusts rich in cobalt have also been known for a considerable time, although interest in them as an economic resource is more recent. They are almost exclusively EEZ deposits, and are found attached to hard rock substrates usually on seamounts, at depths between 800m and 2400m. This attachment leads to obvious problems in recovery or harvesting since the crusts have to be broken off. Crusts contain an average of 1% cobalt but recovered crusts are likely to be diluted with parent rock and are thus unlikely to yield more than the 0.5% cobalt which is typically contained in manganese nodules. The metals in crusts are thought to derive from diffusion with the oxygen minimum zone, which contains elevated levels of both manganese and cobalt. Resource assessments in the region of the Cook Islands, (British Commonwealth, S. Pacific), indicate 930,000 tonnes of cobalt and 630,000 tonnes of nickel. In the Phoenix Island region, crusts are thought to contain 69,000 tonnes of cobalt and 56,000 tonnes of nickel. It has been suggested (Cronan, 1990) that crusts are less likely to become a viable source of cobalt than nodules. Reasons cited include the difficulties in mining technology, and also the available relative abundance of metals, specifically cobalt in nodules.
4.5.1.4 Polymetallic sulphide deposits

Polymetallic sulphide deposits are products of the circulation of seawater through the hot volcanic rocks which well up along spreading ridges of the oceans and back-arc basins. Upon coming in contact with cooler water, the minerals precipitate producing mineral deposits of zinc, copper, lead, barium, silver and gold in widely varying proportions as sulphides and oxides. Some areas where depositional environments were conducive to heavy sedimentation appear to contain several millions of tons of ore and compare with some of the largest massive sulphide deposits that are being mined on land. Except for the Atlantis II Deep in the Red Sea, none of the deposits have been surveyed and sampled sufficiently to determine their grade and tonnage. Deposits are also known from about 100 locations in the Pacific, two in the Atlantic, one in the Mediterranean, one in the Indian Ocean, and in several "deeps" of the Red Sea. Deposits at six sites (Atlantis II Deep, Escanaba Trough, Middle Valley, TAG, seamount at 13° N, and southern Explorer Ridge) are within the size range of deposits that would be mined on land under favourable economic conditions.

Many marine mineral specialists believe that some polymetallic sulphides will be extracted before mining ferromanganese crusts and nodules. Mining will focus on sediments of the Red Sea type. Where polymetallic sulphides occur as loosely consolidated sediments, they should be easier to exploit. The Red Sea sediments measure 10-20m deep within a 5-km-wide and 13-km-long area of c. 56 million m². The sediments contain an estimated 32 million tons of metal and are about 35m thick at the main mine site. Of this total, iron measures 29 %, zinc 1.5 %, copper 0.8 %, and lead 0.1 %. Mining activity will be dependent on an increase in presently unfavourable metal prices, solving technical problems in recovery and processing and environmental and regulatory problems. The resource is substantial, but unfavourable metal prices and problems in recovery and processing make it unlikely that exploitation will begin soon.

Considerable international research effort is also targeted at the various forms of discrete hydrothermal vent structures including black smokers and other chimneys. Research teams from the University of Washington have succeeded in recovering single samples of hydrothermal vent chimneys by means of specialised equipment. A recent (1999), and notable recovery was made by a team from New South Wales, Australia. This structure was recovered from the seabed in the Bismarck Sea, north of Papua New Guinea, by the CSIRO research vessel Franklin under fortuitous circumstances having become lodged in a benthic dredge. Preliminary accounts describe the chimney as having a high gold content as well as containing other economic minerals. It is noted that these research programs are not only focused on the economic potential of contained metals, but have a broad agenda that includes developing greater understanding of all the associated physico-chemical and biological processes. Vent biological communities have generated considerable interest in relation to macrofaunal biomass, and the role of exotic enzyme systems, particularly those of chemotrophic bacteria.

**International Marine Minerals Society**

The International Marine Minerals Society (IMMS) is a professional society whose members share a common interest in various aspects of marine minerals. Founded in 1987, the IMMS now includes a world-wide membership of individuals from industry, government agencies, and academic institutions. The primary objectives of the IMMS, as stated in its bylaws, are:
• To promote and improve the understanding of the origin, distribution, mining, processing, development, and economic assessment of mineral deposits within the province of the global ocean;
• To aid in the exchange of data and other information on an individual basis and through publishing papers and issuing technical reports;
• To sponsor meetings, seminars, and symposia for the timely exchange of information;
• To encourage the prudent development of marine mineral resources, including concern for the environment;
• To encourage and assist young professionals in their study of marine minerals and in the pursuit of their careers, and;
• To encourage, internationally, both basic and applied research in all aspect of marine minerals development.

The IMMS is a co-sponsor of the Underwater Mining Institute (UMI) and holds its annual meetings in conjunction with the UMI. Members of the IMMS receive a bi-annual newsletter, which includes summaries of the latest developments in the field of marine minerals. The 2000 Executive Board includes: President Alexander Malahoff (University of Hawai‘i), Past-President Steven D. Scott (University of Toronto, Canada), President-Elect James R. Hein (U.S. Geological Survey, Menlo Park, CA), Secretary Michael J. Cruickshank (University of Hawai‘i), Treasurer John C. Wiltshire (University of Hawai‘i), and Directors J. Robert Woolsey (University of Mississippi), Peter Herzig (Freiberg University of Mining and Technology, Germany) and Anthony Jones (International Seabed Authority, Jamaica).
4.5.2 Synthesis of the current extent and recoverability of metalliferous nodules and crusts in Irish waters

Very little appears to be known of the occurrence or distribution of manganese nodules in Irish waters. A search of available sample databases (GSI and BGS) returned the following description for a sediment sample that was collected c.100km north east of the Antrim coast (5.33960 deg W, 55.85540 deg N).

"brown mud with bivalves and many manganese nodules"

Despite the scarcity of documentary evidence, occurrences of manganese nodules are apparently not uncommon in Irish waters (Mick Geoghegan, GSI, personal communication). Whilst it is apparent that nodules are present in a variety of locations, the available information gives no hint as to the general or local abundance of these deposits. International experience indicates that for extractive purposes there is a minimum economically viable density of nodules. In the event that such densities were to be proven for Irish waters, the potential for viable extraction would still be heavily dependant on world metal prices and other external factors, including possible advances in extractive technologies. Political and legal issues also have a large impact on investment prospects for deep-sea mining, and many remain to be resolved for areas that may be beyond the 200 mile Irish sovereign limit. Given these uncertainties and the apparent lack of any commercial interest to date, development of this class of resources in Irish waters would appear to be unlikely in the foreseeable future.

Documentary evidence of the existence of polymetallic sulphide deposits in Irish waters is lacking, also the theoretical situation with respect to finding reserves of metalliferous crusts is unpromising. Suitable formative conditions are characteristically found on the upper flanks of Pacific seamounts. Favourable conditions may occur on the flanks of the Hebrides Terrace Seamount part of which falls in Irish waters. Other locations that may support crust formation could exist on exposed rock surfaces in the Rockall Trough and Hatton Basin but only where rates of sediment deposition are extremely low. Considering the general international consensus that nodules are in any case likely to be mined before crusts (Cronan, 1990), there would appear little potential for extraction in the foreseeable future.

4.5.3 RTDI initiatives

In the absence of any appreciable platform of existing work in this field it would appear that reconnaissance resource assessment would form the logical start point for research and development into metalliferous nodule and crust exploitation in Irish waters. Techniques for seabed sediment discrimination have become quite advanced since pioneering work was carried out during the 1980s (de Moustier, 1985) to infer manganese nodule coverage from multibeam acoustic backscatter data. It is likely that work undertaken through the national seabed survey with multibeam sonars will add considerably to the current knowledge base. Discrimination of seabed sediment type is now partially automated and is an inherent feature of several leading OTS sonar processing packages. This process is achieved through the analysis of multiple attributes inherent in acoustic backscatter data, which is backed up by comprehensive ground truthing to assemble an archive of acoustic signatures. There is a possibility that manganese deposits will give rise to sufficiently distinctive signature to enable meaningful discrimination between them and other similar substrates.
Extant (Simrad) systems currently to be deployed during the national seabed survey may be able to provide such classification, however there may also be potential to evaluate the ability of various other proprietary systems to discriminate the presence of manganese nodule beds. Such systems include the RoxAnn hydroacoustic processor, and the newly upgraded return echo processing system, recently been launched by the Quester Tangent Corporation, (Sidney, B.C., Canada) that can be applied to single and multibeam sonars. The chief limitations of such systems are transmission power and the size of beam footprint in deeper water, which obviously limits achievable resolution. The latter organisation has expressed interest in the possible development of collaborative research in this area (Bill Collins-VP Marine, Quester Tangent Corporation, personal communication), and it is understood that the system is part of a package recently installed at the GSI. Another seabed classification system that may be of interest in this area is that currently under development at DERA. This system may be coming under trial in Irish waters in the near future through a joint demonstration project. The system is intended as a top-side processor that can integrate with a range of side-scan sonar systems.

It is clear from international experience in the Pacific that the discovery of nodules (and other deep-sea resources) is only the first step in a long process, where search areas are progressively refined through a succession of increasingly detailed phases of resource evaluation. These later phases will rely on increasingly dense coverage of photographic and physical sampling for ground truth information. This reliance on groundtruthing is a recurrent theme in respect of many classes of seabed resource and other types of seabed research. The design approach adopted by the French in developing the ED 1 free-fall grab and photographic device has much to offer as a concept. Although some loss of absolute positional accuracy may result from the autonomous operating technique of this system, this disadvantage is in practice likely to be considerably offset by dispensing with the need for prolonged periods of vessel immobility that are experienced with conventionally lowered sampling devices. Harvesting of nodules has been attempted by means of large (330t) benthic collection machines (see also diamonds in section 4.4). An example of this type of device is shown in Figure 5.3 below.

Figure 5.3 Artists representation of a potential benthic harvesting device for manganese nodules.

Cronan (1990) cites a continuing need for improved types of sensors for finding and assessing seafloor hydrothermal systems. These include optical image systems and water column sensors (for detecting evidence of hydrothermal gas anomalies), as well as in-situ
samplers such as drills and corers. Although techniques for extraction of metals from seabed derived ores have been fully developed, processing is regarded as the most costly phase in nodule mining production. There may thus be potential to develop or modify existing Irish metallurgical expertise to reduce the high energy requirements involved.
4.6. Maërl

4.6.1 Current international experience with respect to the exploration and development of maërl resources

4.6.1.1 Characteristics and formation of maërl deposits

The term “maërl” is a Breton term originally used to describe gravels formed by unattached coralline algae off the north-west coast of France (Lemoine, 1910). The term describes thick sediment accumulations of coralline algae that are characterised by calcified cell walls that form a rigid or solid skeleton. There are a number of species of coralline algae that are divided into two general types; the erect geniculate coralline algae, and the non-geniculate encrusting type, it is the latter type, which are the maërl-forming species. These maërl species are very slow growing algae (e.g., 876g m$^{-2}$yr$^{-1}$, Poitin et al., 1990) and some beds have been estimated to be upwards of 6000 years old (Friedwald et al., 1991).

Collection of maërl has been carried out on a small scale in Europe for some time, and in Ireland the practice can be traced back to the 17th century. An early reference to maërl beds in Britain was made by Ray (1690, cited by Irvine & Chamberlain, 1994):

"Corallium album pumilum nostras or small white coral. It is found plentifully in the ooze dredged out of Falmouth Haven to manure their lands in Cornwall."

In France also, maërl has been utilised for several centuries (Cabioch, 1969). The main uses of maërl have been and still remain to this day as a cost effective source of calcium soil additive for agriculture and horticulture (Briand, 1989). Other uses to which maërl has been put include as an animal fodder additive, acid water treatment, biological de-nitrification, drinking water potabilization, toxin elimination, pharmaceuticals, cosmetics, bone surgery as well as chemical processing in the nuclear industry. Although historical levels of extraction were quite high, present day extraction levels in Irish waters are low, at a licensed level of 8,000 tonnes per annum. This compares to a French extraction rate of as much as 600,000 tonnes per annum. In fact, maërl extraction forms a major part of the French seaweed industry, both in terms of tonnage and value of harvest. Levels of extraction in the UK have been up to 30,000 tonnes per annum (1975 to 1991), all of which was commercially harvested from the Fal Estuary (Cornish Calcified Seaweed Company). No recent records of extraction could be obtained and individuals within the ‘Crown Estate’ have indicated to the research team that very little new extraction of maërl was being undertaken as a result of new environmental legislation. Most research work on maërl to date has been based on the three main areas where commercial exploitation is carried out, namely Brittany, Cornwall and the west of Ireland. In recent times, maërl has been legally protected under several designations for example as a habitat under the EC Habitats Directive 1992. In addition, the two main maërl-bed forming species (Lithothamnion corallioides and Phymatolithon calcareum) have both been included on international lists of habitats (and on the EU Habitats Directive, Annex V) which would merit protection or at least some form of management structure to preserve their community and structural diversity. Several types of human impact on maërl beds are currently being studied by the BIOMÆRL program. Factors being examined include demersal fishing gear, aquaculture, and eutrophication and maërl extraction.
4.6.2 Synthesis of their current extent and recoverability in Irish waters

Recent research has indicated that almost all of the Irish maërl deposits lie along the west coast with the majority off counties Cork, Kerry and Galway (De Grave et al., 2000). Deposits occur as far north as Donegal, though many of these are in water depths greater than 30m and have not been confirmed in recent times. Unconfirmed reports indicate offshore deposits to be present at depths up to 95m. Current depths to which extraction of maërl is commercially viable lie at less than 25-30 meters. The distribution of maërl beds in Irish waters is shown in Figure 5.3.

The recent research undertaken as part of the 1995 Marine Research Measure put a tentative estimate of a potential $3 \times 10^6$ m$^3$ of maërl as being available for exploitation within Irish waters$^2$. Threats to the living deposits come from the direct and indirect affects of dredging, scallop trawling, mussel aquaculture, boat mooring as well as pollution.

Only one commercial venture has developed around the extraction of maërl in Ireland. This is based on the maërl beds in Bantry Bay, which although they have been subject to small scale local harvesting for many decades, have, since the early 1990s been exploited as part commercial activities of Celtic Sea Minerals company. Under licence from the Department of the Marine, Celtic Sea Minerals extracts at a rate of 8,000 tonnes per year from Lonehort point, a site off the north east part of Bere Island, County Cork. Established in 1991, the company extracts maërl using a trailer suction dredger, by means of which the material lifted hydraulically by suction through a drag arm and pumped into a hopper bin. Material is extracted at a rate of 130 tonnes a day and transported for onshore processing at a commercial site on Dinnish Island. The company currently employs a total of 15 and produces a range of branded materials including: AquaMin, Aqua Min F, Aqua Cal, Aqua Min TG, Acid Buf and Dri-Li. Presently some 60% of their product is exported each year to markets in the US, the Middle East and Europe. Competitors come principally from the UK and France. The main barriers to continued success and further development of this industry relate to product value addition and marketing. This provides the focus for much of the companies current research and development effort.

4.6.3 RTDI initiatives

Research at the international level is concerned with many aspects related to maërl both from a commercial resource perspective and biological perspective as a relatively specific biotope and in view of its commercial aspects.

There are many gaps in the present knowledge of maërl beds in Ireland that will require to be addressed in order to devise appropriate resource management strategies. The gaps vary from simple issues regarding the exact distribution of the various maërl forming species and how old these beds are, to more complex issues with respect to the effect of environmental change on the structure of maërl communities. One of the most serious questions with regards to management of maërl as a resource as well as a biotope concerns growth rates of maërl species and longevity of maërl beds. Research into the growth rates of different maërl-forming coralline algae under varying conditions should be regarded as a priority.

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$^2$ This figure is based on an estimated average thickness of maërl of 2m in Irish waters as determined by De Grave et al., 2000.
Figure 5.3 Distribution of Maerl beds in Irish waters (source, De Grave et al, 1999)
More specific information on the use of maërl beds as nursery areas for commercially harvested species might be very useful in gaining support from the public and other users for maërl conservation. The issue of deep-water maërl beds was highlighted in a recent Marine Research Measure as requiring future attention. Research is required to detail the location and extent of these deep-water sites as well as to biologically quantify the sites. A pan-European approach to maërl bed conservation is advocated by the BIOMAËRL program (Birkett et al., 1998). An index based on various biotic and abiotic measures would represent the overall biodiversity status of a particular maërl bed. Such an index would be capable of being monitored over time to provide a check on environmental change, especially any deterioration. It would also supply a mapable, objectively derived descriptor that, by virtue of being independent of species composition would be capable of direct comparison at a pan-European scale.

In terms of commercial activities based around maërl, access to the resource itself, (thus supply of raw material) is not a limiting factor. Current rates of extraction are low in relation to the estimated volume of locally available resources. The main problems facing the company relate to the costs and technical aspects of new product development, and enhancement of current products. Research and development costs are high in this sector, although the future commercial viability may depend on the realisation of new and innovative uses for this raw material. Collaboration with university-based groups in areas such as Food Science & Technology may be an appropriate avenue through which these objectives could be achieved.
Appendices
USGS Reassesses Potential World Petroleum Resources: Oil Estimates Up, Gas Down

The U.S. Geological Survey's latest assessment of undiscovered oil and gas resources of the world reports an increase in global energy resources, with a 20 percent increase in undiscovered oil and a slight decrease in undiscovered natural gas. This assessment estimates the volume of oil and gas, exclusive of the U.S., that may be added to the world's reserves in the next 30 years.

"There is still an abundance of oil and gas in the world," said Thomas Ahlbrandt, USGS (2000) World Petroleum Assessment project chief. "Since oil became a major energy source about 100 years ago, about 539 billion barrels of oil have been produced outside of the U.S. We now estimate the total amount of future technically recoverable oil, outside the U.S., to be about 2120 billion barrels."

The assessment results indicate that there is more oil and gas in the Middle East and in the offshore areas of western Africa and eastern South America than previously reported, less oil and gas in Canada and Mexico, and significantly lower volumes of natural gas in the Former Soviet Union.

With the evolution of technology and new understandings of petroleum systems, the USGS World Petroleum Assessment 2000 is the first of its kind to provide a rigorous geologic foundation for estimating undiscovered energy resources for the world. The results have important implications for energy prices, policy, security, and the global resource balance.

"These assessments provide a snapshot of current information about the location and abundance of undiscovered oil and gas resources at a point in history. Such an overview provides exploration geologists, economists and investors a general picture of where oil and gas resources are likely to be developed in the future," said Gene Whitney, USGS Energy Team Chief Scientist. The USGS periodically estimates the amount of oil and gas remaining to be found, and since 1981, the last three of these studies has shown a slight increase in the combined volume of identified reserves and undiscovered resources.

In USGS World Petroleum Assessment 2000, the world was divided into approximately one thousand petroleum provinces, based primarily on geologic factors, and then grouped into eight regions roughly comparable to the eight economic regions defined by the U.S. State Department. Significant petroleum resources are known to exist in 406 of the 1000 geologic provinces.

Additionally, estimates of reserve growth at the world level were made for the first time. Reserve growth estimates nearly equal those of undiscovered resources. Reserve growth results from the following:
As drilling and production within discovered fields progresses, new pools or reservoirs are found that were not previously known.

Advances in exploration technology make it possible to identify new targets within existing fields.

Advances in drilling technology make it possible to recover oil and gas not previously considered recoverable in the initial reserve estimates.

Enhanced oil recovery techniques increase the recovery factor for oil and thereby increase the reserves within existing fields.

Ahlbrandt and his colleagues will discuss preliminary results of the World Petroleum Assessment with the International Energy Agency in Paris on March 21. The final report will be released at the World Petroleum Congress in Calgary in June. Supporting geological data have already been released for the Former Soviet Union; Sub-Saharan Africa and North Africa; the Arabian Peninsula; South Asia; the Asia Pacific Region; South America; and Iran.

As the nation's largest water, earth and biological science, and civilian mapping agency, the USGS works in cooperation with more than 2,000 organisations across the country to provide reliable, impartial scientific information to resource managers, planners, and other customers. This information is gathered in every state by USGS scientists to minimise the loss of life and property from natural disasters, contribute to the sound conservation and the economic and physical development of the nation's natural resources, and enhance the quality of life by monitoring water, biological, energy, and mineral resources.

USGS
In-depth information about USGS programs may be found on the USGS home page at http://www.usgs.gov. To receive the latest USGS news releases automatically by e-mail, send a request to listproc@listserver.usgs.gov. Specify the listserver(s) of interest from the following names: water-pr; geologic-hazards-pr; biological-pr; mapping-pr; products-pr; lecture-pr. In the body of the message write: subscribe (name of listserver) (your name). Example: water-pr joe smith.

Table 1x shows volumes of undiscovered world petroleum, by commodity, from this assessment (mean values, exclusive of the United States) and the previous USGS assessment

<table>
<thead>
<tr>
<th>Commodity</th>
<th>USGS 1993 Assessment (Masters, 1994)</th>
<th>USGS 2000 Assessment (this study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undiscovered oil</td>
<td>539 billion barrels</td>
<td>649 billion barrels</td>
</tr>
<tr>
<td>Undiscovered natural gas</td>
<td>915 BBOE</td>
<td>778 BBOE</td>
</tr>
<tr>
<td>Undiscovered natural gas liquids</td>
<td>90 BBOE</td>
<td>207 BBOE</td>
</tr>
<tr>
<td>World Total</td>
<td>1544 BBOE</td>
<td>1634 BBOE</td>
</tr>
</tbody>
</table>

*BBOE = billion barrels of oil equivalent
### Table 2x. Volumes of undiscovered oil and undiscovered natural gas by region, including percentages of world totals (mean values, exclusive of the United States).

<table>
<thead>
<tr>
<th>Region</th>
<th>Undiscovered oil billion barrels</th>
<th>Percent of world total</th>
<th>Undiscovered natural gas (trillion cubic feet)</th>
<th>Percent of world total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Former Soviet Union</td>
<td>116</td>
<td>17.9 %</td>
<td>1611</td>
<td>34.5 %</td>
</tr>
<tr>
<td>2: Middle East and North Africa</td>
<td>230</td>
<td>35.4 %</td>
<td>1370</td>
<td>29.3 %</td>
</tr>
<tr>
<td>3: Asia-Pacific</td>
<td>30</td>
<td>4.6 %</td>
<td>379</td>
<td>8.1 %</td>
</tr>
<tr>
<td>4: Europe</td>
<td>22</td>
<td>3.4 %</td>
<td>312</td>
<td>6.7 %</td>
</tr>
<tr>
<td>5: North America*</td>
<td>70</td>
<td>10.9 %</td>
<td>154</td>
<td>3.3 %</td>
</tr>
<tr>
<td>6: Central and South America</td>
<td>105</td>
<td>16.2 %</td>
<td>487</td>
<td>10.4 %</td>
</tr>
<tr>
<td>7: Sub-Saharan Africa and Antarctica</td>
<td>72</td>
<td>11.0 %</td>
<td>235</td>
<td>5.0 %</td>
</tr>
<tr>
<td>8: South Asia</td>
<td>4</td>
<td>0.6 %</td>
<td>120</td>
<td>2.6 %</td>
</tr>
<tr>
<td>World Total*</td>
<td>649</td>
<td></td>
<td>4669</td>
<td></td>
</tr>
</tbody>
</table>

*Exclusive of the United States

### Table 3x. Estimates of reserve growth for various petroleum commodities for the world (exclusive of the United States).

<table>
<thead>
<tr>
<th>Commodity Reserve Growth</th>
<th>USGS 2000 Assessment (this study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil reserve growth</td>
<td>612 billion barrels</td>
</tr>
<tr>
<td>Natural gas reserve growth</td>
<td>551 BBOE (3,305 trillion cubic feet)</td>
</tr>
<tr>
<td>Natural gas liquids reserve growth</td>
<td>42 BBOE</td>
</tr>
</tbody>
</table>

### Table 4x. USGS World Petroleum Assessment 2000 (excluding U.S.).

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Mean Undiscovered Conventional Resources (^1) (BBOE)</th>
<th>Mean Conventional Reserve Growth (^1) (BBOE)</th>
<th>Mean Remaining Reserves (^2, 3) (BBOE)</th>
<th>Mean Cumulative Production (^2, 3) (BBOE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>649</td>
<td>612</td>
<td>859</td>
<td>539</td>
</tr>
<tr>
<td>Gas</td>
<td>778</td>
<td>551</td>
<td>770</td>
<td>150</td>
</tr>
<tr>
<td>NGL</td>
<td>207</td>
<td>42</td>
<td>68</td>
<td>7</td>
</tr>
</tbody>
</table>

\(^1\) This study
\(^2\) Petroconsultants, 1996
\(^3\) NRG Associates, 1995
The following text summarises the response to a request for further information from the USGS:

This study provides estimates of the remaining undiscovered conventional petroleum resources and additions to the amount of petroleum reserves anticipated through field (also called reserve) growth for the world, exclusive of the U.S.A. The first publications to be released are a series of CD-ROMs listed below:

- A series of OFR's with maps showing geology, oil and gas fields, and geologic provinces for: Sub-Saharan Africa and North Africa, OFR 97-470A
- Arabian Peninsula, OFR 97-470B
- South Asia, OFR 97-470C
- South America, OFR 97-470D
- The Former Soviet Union, OFR 97-470E
- Asia Pacific Region, OFR 97-470F
- Iran, OFR 97-470G

Europe and North America are next in this series and should be out soon. The coordinator for the European portion of the assessment is Don Gautier, located in our offices in Menlo Park, California. His contact information is: e-mail, gautier@usgs.gov, phone, 650-329-4909. In June of this year the actual assessment numbers will be published on CD-ROM and released at the World Petroleum Congress, in Calgary, Alberta, Canada. All of these publications and the most recent press release with world and region estimates are available on a website at http://energy.usgs.gov/. This assessment only considered conventional petroleum resources and so methane hydrates were not included. The next phase of our world assessment activities will address unconventional (including methane hydrates and coalbed methane) resources, though probably not in the time frame you need if your study is in its concluding stages. We have several people who are involved in active research on methane hydrates, for gas hydrates in the marine environment, Bill Dillon, located in our offices in Woods Hole, Massachusetts, would be the logical choice. His contact information is:

email, bdillon@usgs.gov,
phone, 508-457-2224.

Appendix II

Irish Offshore Operators Association

Formed in 1995, this group is an umbrella organisation that provides a focal point for liaison between companies participating in Ireland's oil and gas industry and between industry itself, other interested bodies and the relevant government authorities.

<table>
<thead>
<tr>
<th>Name of Company</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agip Ireland</td>
<td>BV, Wellington Circle, Redmoss, Aberdeen AB12 3JG, Scotland</td>
</tr>
<tr>
<td>BG Exploration and Production Ltd</td>
<td>100 Thames Valley Park Drive, Reading, Berkshire RG6 1PT, England.</td>
</tr>
<tr>
<td>Chevron Europe</td>
<td>43-45 Portman Square, London W1H 0AN, England.</td>
</tr>
<tr>
<td>Elf Petroleum Ireland BV</td>
<td>Claymore Drive, Bridge of Don, Aberdeen AB23 8GB, Scotland</td>
</tr>
<tr>
<td>Enterprise Oil plc</td>
<td>Herbert Park Lane, Ballsbridge, Dublin 4</td>
</tr>
<tr>
<td>Marathon International Petroleum Hibernia</td>
<td>Mahon Industrial Estate, Blackrock, Cork</td>
</tr>
<tr>
<td>Phillips Petroleum Exploration Ireland</td>
<td>Regus House, Harcourt Road, Dublin 2.</td>
</tr>
<tr>
<td>Providence Resources Plc</td>
<td>60 Merrion Road, Ballsbridge, Dublin 4</td>
</tr>
<tr>
<td>Statoil Exploration (Ireland) Ltd.</td>
<td>Statoil House, 6 George's Dock, IFSC, Dublin 1</td>
</tr>
<tr>
<td>Total Oil Marine plc</td>
<td>Crawpeel Road, Altens, Aberdeen AB9 2AG, Scotland</td>
</tr>
</tbody>
</table>
Petroleum Exploration and Development Offshore Ireland

Acreage Position on 1 August 1999

This appendix summarises the licensing situation with respect to petroleum leasing as it was on August 1st 1999. A short definition of the main types of licenses is followed by a series of tables setting out the details of each license that is held.

**Petroleum Exploration License**: vests in the holder the exclusive right of carrying out exploration for petroleum in the licensed area.

**Standard Exploration License**: is issued for a period of six years in respect of an area with water depths up to 200 metres.

**Deepwater Exploration License**: is issued for a period of twelve years in respect of areas in which the water depth exceeds 200 metres.

**Frontier Exploration Licence**: may be issued in respect of an area with special difficulties related to physical environment, geology or technology where such areas specified and announced by the Minister for the Marine and Natural Resources as a 'Frontier Area'. This licence type is valid for a period of not less than 15 years, comprising a maximum of four phases.

<table>
<thead>
<tr>
<th>Licence</th>
<th>Licence Period</th>
<th>Block No.</th>
<th>Participants (*Operator)</th>
<th>% Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/93 Deepwater</td>
<td>1 January 1993 - 31 December 2004</td>
<td>18/25, 18/29, 18/30, 27/4, 27/5 &amp; 27/9</td>
<td>* Enterprise Oil plc; Saga Petroleum Ireland Limited; Statoil Exploration (Ireland) Limited Marathon International Petroleum Hibernia Limited</td>
<td>45% 21.5% 15% 18%</td>
</tr>
<tr>
<td>2/94 Frontier</td>
<td>15 March 1994 - 14 March 2010</td>
<td>12/2, 12/3, 12/7 &amp; 12/8</td>
<td>* Enterprise Oil plc. Agip Ireland BV.</td>
<td>60% 40%</td>
</tr>
<tr>
<td>3/94 Frontier</td>
<td>15 March 1994 - 14 March 2010</td>
<td>18/14, 18/15, 18/19 &amp; 18/20</td>
<td>* Enterprise Oil plc; Saga Petroleum Ireland Limited; Statoil Exploration (Ireland) Limited Marathon International Petroleum Hibernia Limited</td>
<td>45% 21.5% 15% 18%</td>
</tr>
<tr>
<td>5/94 Frontier</td>
<td>15 March 1994 - 14 March 2010</td>
<td>11/29, 19/2, 19/3, 19/4, 19/7, 19/8, 19/11, 19/12, 19/16, 19/17 &amp; 19/21</td>
<td>* Statoil Exploration (Ireland) Limited; ARCO Ireland Offshore Inc.; Murphy Ireland Offshore, Ltd; Enterprise Oil plc.</td>
<td>30% 30% 25% 15%</td>
</tr>
<tr>
<td>2/95 Frontier</td>
<td>15 March 1995 - 15 March 2010</td>
<td>26/28 &amp; 26/29</td>
<td>* Statoil Exploration (Ireland) Limited</td>
<td>100%</td>
</tr>
</tbody>
</table>
## PETROLEUM EXPLORATION LICENCES (contd.)

<table>
<thead>
<tr>
<th>Licence</th>
<th>Licence Period</th>
<th>Block No.</th>
<th>Participants</th>
<th>% Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/95 Frontier</td>
<td>15 March 1995 - 15 March 2010</td>
<td>35/19, 35/29, 35/30, 36/21, 36/26, 44/4 &amp; 44/5</td>
<td>* Marathon International Petroleum Hibernia Limited; Phillips Petroleum Company United Kingdom Limited</td>
<td>50% 50%</td>
</tr>
<tr>
<td>8/95 Frontier</td>
<td>15 March 1995 - 15 March 2010</td>
<td>34/24, 34/25, 34/30, 35/21, 35/23(p) &amp; 35/24</td>
<td>* Statoil Exploration (Ireland ) Limited; Conoco (U.K.) Ltd; ARCO Ireland Offshore Inc; Dana Petroleum (E&amp;P) Limited</td>
<td>37.931% 27.586% 20.690% 13.793%</td>
</tr>
<tr>
<td>9/95 Frontier</td>
<td>15 March 1995 - 15 March 2010</td>
<td>35/17, 35/22, 35/23(p) &amp; 35/28</td>
<td>* Total Oil Marine plc.; DSM Energy (Ireland) B.V.; Conoco (UK) Limited; ARCO Ireland Offshore Inc.</td>
<td>50% 10% 30% 10%</td>
</tr>
<tr>
<td>11/95 Standard</td>
<td>1 September 1995 - 31 August 2001</td>
<td>49/23 &amp; 49/24(p)</td>
<td>* Frontier Resources International Inc.; Sherritt International Oil and Gas Limited</td>
<td>50% 50%</td>
</tr>
<tr>
<td>1/97 Standard</td>
<td>1 May 1997 - 30 April 2003</td>
<td>63/3(s), 63/4, 63/8, 63/9 &amp; 63/10</td>
<td>* EDC (Europe) Limited; Prospeccion Y Desarrollo de Hidrocarburos Espanoles S.A. (PYDHESA); Medusa Oil Limited</td>
<td>57% 28.5% 14.5%</td>
</tr>
<tr>
<td>2/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>18/9, 18/10 &amp; 19/6</td>
<td>* ARCO Ireland Offshore Inc.; BG Exploration &amp; Production Ltd; Anadarko Ireland Company</td>
<td>33.33% 33.33% 33.33%</td>
</tr>
<tr>
<td>3/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>16/27, 25/1(p), 25/2, 25/6, 75/9(p) &amp; 75/10</td>
<td>* BG Exploration &amp; Production Ltd; ARCO Ireland Offshore Inc.; Anadarko Ireland Company</td>
<td>33.33% 33.33% 33.33%</td>
</tr>
<tr>
<td>4/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>25/1(p), 75/4, 75/5, 75/8 &amp; 75/9(p)</td>
<td>* Elf Petroleum Ireland BV; Phillips Petroleum Exploration Ireland</td>
<td>50% 50%</td>
</tr>
<tr>
<td>5/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>5/18, 5/23 &amp; 5/28</td>
<td>* Elf Petroleum Ireland BV; Phillips Petroleum Exploration Ireland; British Borneo International Ltd</td>
<td>50% 30% 20%</td>
</tr>
</tbody>
</table>
### PETROLEUM EXPLORATION LICENCES (contd.)

<table>
<thead>
<tr>
<th>Licence</th>
<th>Licence Period</th>
<th>Block No.</th>
<th>Participants</th>
<th>% Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>5/16, 5/17, 5/21, 5/22, 5/26 &amp; 5/27</td>
<td>* Operator: Enterprise Oil plc; Mobil Oil North Sea Ltd; Murphy Ireland Offshore, Ltd; ARCO Ireland Offshore Inc;</td>
<td>25% 25% 25% 25%</td>
</tr>
<tr>
<td>8/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>75/21, 75/26, 82/25 &amp; 82/30</td>
<td>* Operator: Phillips Petroleum Exploration Ireland; Agip Ireland BV</td>
<td>50% 50%</td>
</tr>
<tr>
<td>9/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>83/9, 83/10, 83/14 &amp; 83/15</td>
<td>* Operator: Phillips Petroleum Exploration Ireland; Elf Petroleum Ireland BV</td>
<td>50% 50%</td>
</tr>
<tr>
<td>10/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>83/13, 83/18, 83/19 &amp; 83/20</td>
<td>* Operator: Saga Petroleum Ireland Ltd; Total Oil Marine plc; Statoil Exploration (Ireland) Limited; Shell EP Atlantic BV</td>
<td>30% 20% 25% 25%</td>
</tr>
<tr>
<td>11/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>1/17, 1/18, 1/21, 1/22, 1/23, 1/26, 1/27, 77/4, 77/5, 78/25, 78/29 &amp; 78/30</td>
<td>* Operator: Shell EP Atlantic BV; Statoil Exploration (Ireland) Limited; BP Exploration Operating Company Ltd</td>
<td>33.33% 33.33% 33.33%</td>
</tr>
<tr>
<td>12/97 Frontier</td>
<td>4 June 1997 - 3 June 2013</td>
<td>10/30, 11/26, 18/4, 18/5 &amp; 19/1</td>
<td>* Operator: Statoil Exploration (Ireland) Limited; Shell EP Atlantic BV</td>
<td>50% 50%</td>
</tr>
<tr>
<td>1/99 Frontier</td>
<td>15 March 1999 - 14 March 2014</td>
<td>43/19, 43/20, 43/24, 43/25, 43/28 &amp; 43/29</td>
<td>* Operator: Agip Ireland BV</td>
<td>100%</td>
</tr>
<tr>
<td>2/99 Frontier</td>
<td>15 March 1999 - 14 March 2014</td>
<td>44/18, 44/23, 44/24, 44/29, &amp; 44/30</td>
<td>* Operator: Elf Petroleum Ireland BV</td>
<td>100%</td>
</tr>
</tbody>
</table>
AVAILABILITY OF ACREAGE

Since the acreage position report was published in June, 1999 blocks 33/17(p), 33/18, 33/22 (p) located in the Kish Bank Basin and 49/12 located in the North Celtic Sea have been relinquished and will be available for licensing under the 'open door' system.

LICENSING OPTIONS

A Licensing Option gives the holder the first right to an Exploration Licence over all or part of the area covered by the Option.

<table>
<thead>
<tr>
<th>Option No.</th>
<th>Expiry Date</th>
<th>Blocks</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>96/2</td>
<td>Option has expired; application for Lease Undertaking under consideration</td>
<td>49/13(p), 49/14(p), 49/18(p) and 49/19(p)</td>
<td>Providence Resources plc</td>
</tr>
<tr>
<td>98/1</td>
<td>13 May 1999 (application for extension under consideration)</td>
<td>50/11</td>
<td>Providence Resources plc; Island Petroleum Developments Ltd</td>
</tr>
<tr>
<td>99/2</td>
<td>31 March 2001</td>
<td>13/4 (S), 13/8 (S), 13/9, 13/13 (N) and 13/14 (N)</td>
<td>Enterprise Oil plc</td>
</tr>
</tbody>
</table>

PETROLEUM LEASES

A Petroleum Lease vests in the lessee the exclusive right to produce petroleum from the leased areas.

<table>
<thead>
<tr>
<th>Fields</th>
<th>Commencement Date</th>
<th>Blocks</th>
<th>Participants</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helvick</td>
<td>1 May 1998</td>
<td>49/9 (p)</td>
<td>Providence Resources plc</td>
<td>Providence Resources plc</td>
</tr>
</tbody>
</table>
PETROLEUM PROSPECTING LICENCES

A Petroleum Prospecting Licence is non-exclusive and confers the right to carry out exploration in any area where an Exploration Licence or Petroleum Lease is not in force.

<table>
<thead>
<tr>
<th>Licence No.</th>
<th>Period of Years</th>
<th>Licence From</th>
<th>Licensee</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/96</td>
<td>3</td>
<td>13/6/96 (extended to 12/6/2001)</td>
<td>P.G.S. Exploration (UK) Ltd.</td>
</tr>
<tr>
<td>2/97</td>
<td>3</td>
<td>1/6/97</td>
<td>Enterprise Oil plc</td>
</tr>
<tr>
<td>3/97</td>
<td>3</td>
<td>6/8/97</td>
<td>Phillips Petroleum Exploration Ireland</td>
</tr>
<tr>
<td>4/97</td>
<td>3</td>
<td>8/8/97</td>
<td>Fina Petroleum Developments Limited</td>
</tr>
<tr>
<td>5/97</td>
<td>3</td>
<td>10/9/97</td>
<td>Saga Petroleum Ireland Limited</td>
</tr>
<tr>
<td>1/98</td>
<td>3</td>
<td>1/1/98</td>
<td>Providence Resources plc</td>
</tr>
<tr>
<td>3/98</td>
<td>3</td>
<td>15/5/98</td>
<td>Elf Exploration UK PLC</td>
</tr>
<tr>
<td>4/98</td>
<td>3</td>
<td>1/10/98</td>
<td>Chevron Ireland</td>
</tr>
<tr>
<td>2/99</td>
<td>3</td>
<td>25/5/99</td>
<td>Fugro-Geoteam AS</td>
</tr>
</tbody>
</table>

ONSHORE PETROLEUM PROSPECTING LICENCE

<table>
<thead>
<tr>
<th>Licence No.</th>
<th>Licence Period</th>
<th>Licence area</th>
<th>Participants</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON 1/97</td>
<td>1 December 1997-30 November 2000</td>
<td>1960 km² over North West Carboniferous Basin</td>
<td>S. Morrice and Associates LLC; Priority Oil and Gas LLC</td>
<td>S. Morrice and Associates LLC</td>
</tr>
</tbody>
</table>
## Appendix III

### ONSHORE LICENSING OPTIONS

<table>
<thead>
<tr>
<th>Option No.</th>
<th>Expiry date</th>
<th>Area</th>
<th>Participants</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>98/1 (Sligo)</td>
<td>30 June 1999 (application for extension under consideration)</td>
<td>411 km² over North West Carboniferous Basin</td>
<td>S. Morrice and Associates LLC; Priority Oil and Gas LLC</td>
<td>S. Morrice and Associates LLC</td>
</tr>
<tr>
<td>98/2 (Lough Allen)</td>
<td>30 June 1999 (application for extension under consideration)</td>
<td>1549 km² over North West Carboniferous Basin</td>
<td>S. Morrice and Associates LLC; Priority Oil and Gas LLC</td>
<td>S. Morrice and Associates LLC</td>
</tr>
</tbody>
</table>

### 1999 SEISMIC SURVEYS

<table>
<thead>
<tr>
<th>OPERATOR</th>
<th>CONTRACTOR</th>
<th>VESSEL</th>
<th>Km</th>
<th>SURVEY AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fugro-Geoteam AS</td>
<td>Fugro-Geoteam AS</td>
<td>Geo Scanner</td>
<td>2692</td>
<td>Donegal Basin</td>
</tr>
<tr>
<td>Elf Petroleum Exploration Ireland BV</td>
<td>Geco-Prakla (UK) Limited / Delif Geophysical BV</td>
<td>Professor Polshkov</td>
<td>237</td>
<td>Rockall Trough</td>
</tr>
<tr>
<td>Elf Petroleum Exploration Ireland BV</td>
<td>Geco-Prakla (UK) Limited / Delif Geophysical BV</td>
<td>Professor Polshkov</td>
<td>459</td>
<td>Rockall Trough</td>
</tr>
<tr>
<td>Elf Petroleum Exploration Ireland BV</td>
<td>Geco-Prakla (UK) Limited / Delif Geophysical BV</td>
<td>Professor Polshkov</td>
<td>459</td>
<td>South Porcupine Basin</td>
</tr>
</tbody>
</table>

### DRILLING ACTIVITIES

<table>
<thead>
<tr>
<th>OPERATOR</th>
<th>AREA</th>
<th>LOCATION</th>
<th>RIG</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise Oil</td>
<td>Slyne Trough</td>
<td>18/25-1</td>
<td>Sedco 711</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Marathon</td>
<td>Celtic Sea</td>
<td>48/25-3</td>
<td>Glomar Artic 111</td>
<td>Re-entered and completed</td>
</tr>
</tbody>
</table>

### COMPANIES ADDRESSES

- *Anadarko Ireland Company*, The Atrium, PO Box 576, Harefield Road, Upsbridge, Middlesex UB8 1YH, UK.
- *ARCO Ireland Offshore Inc*, London Square, Cross Lanes, Guildford, Surrey GU1 1UE, England.
- *BG Exploration and Production Ltd*, 100 Thames Valley Park Drive, Reading, Berkshire RG6 1PT, England.
- *Centrica Resources Limited*, Energy Management Group, Charter Court, 50 Windsor Road, Slough, Berkshire, SL1 2HA, England.
Appendix III

DSM Energy Ireland BV, PO Box 6500, 6401 JH Heerlen, The Netherlands.

EDC (Europe) Limited, Suffolk House, 154 High Street, Sevenoaks, Kent TW13 1XE, England.

Elf Petroleum Ireland BV, 1 Claymore Drive, Bridge of Don, Aberdeen AB23 8GB, Scotland.

Enterprise Oil plc, 4th Floor Embassy House, Herbert Park Lane, Ballsbridge, Dublin 4.


Frontier Resources International Inc., 10375 Richmond Avenue, Suite 1670, Houston, Texas 77042, U.S.A.


Island Petroleum Developments Ltd, Clifton House, Lower Fitzwilliam Street, Dublin 2.

Marathon International Petroleum Hibernia Ltd., Mahon Industrial Estate, Blackrock, Cork.


Mobil Oil North Sea Ltd., Mobil Court, 3 Clements Inn, London WC2A 2EB, England.

S. Morrice & Associates Ltd, 511, 16th Street, Suite 300, Denver, CO 80202, U.S.A.


PGS Exploration (UK) Ltd., PGS Court, Halfway Green, Walton on Thames, Surrey KT12 1RS, England.

Phillips Petroleum Exploration Ireland, Phillips Quadrant, 35 Guilford Road, Woking, Surrey GU22 7QT, England.

Priority Oil & Gas LLC, 633 17th Street, Suite 1520, Denver, CO 80202, U.S.A.

Providence Resources Plc, 60 Merrion Road, Ballsbridge, Dublin 4.

PYDHESA, C/Alfonso XII, 15, 28014 Madrid, Spain.


Sherrit International Oil and Gas Limited, 10101-114 Street, Fort Saskatchewan, Alberta T8L 2P2, Canada.


TGS-Nopec (UK) Ltd, Graylaw House, 21/21A Goldington Road, Bedford MK40 3JY, England.

Total Oil Marine plc, Crawpeel Road, Altens, Aberdeen AB9 2AG, Scotland.
Appendix IV

Minutes of Meeting held at Petroleum Affairs Division, DOMNR.

Date of meeting: Wed 1st December 1999.

In attendance were:
- Pat Ryan-PAD
- Keith Robinson-PAD
- Yvonne Shields-Marine Institute
- Gerry Sutton-Coastal Resources Centre.

**Context of meeting:** The meeting was held at the request of Pat Ryan in order to address issues that had arisen in relation to correspondence issued by the CRC in the course of conducting research work for the Marine Institute. One of the three objectives of this project is as follows

- An assessment of the current status of the offshore hydrocarbons sector in Ireland with a summary review of the role and capabilities of the principal support industries and agencies, and identification of the scope of RTDI opportunities for Irish researchers in this context.

It was felt from the CRC perspective that a meeting was timely in order to establish the extent of information available through PAD that would be pertinent to achieving the objectives of the project.

**Progress of meeting:**

The meeting was opened by Pat Ryan (PR) who expressed reservations in relation to a circular letter that had been sent by CRC to a number of oil companies. It was felt that this direct approach to a wide range of oil companies, some of whom were currently engaged in negotiations or otherwise sensitive situations with respect to their continued presence in the Irish Offshore Sector, was not wholly appropriate, and that the letter could lead to confusion arriving out of context from the CRC rather than through established lines of communication i.e. PAD or Enterprise Ireland.

Y.Shields (YS) stated that it was unfortunate that established protocol had been circumvented at the commencement of the project, and this was in part due to the upheaval of MI restructuring and loss of the head of the marine technology section with responsibility for this area.

YS described the general context, and general objectives of the seabed resources project from the MI perspective, stating that the main thrust of the project was to establish the research priorities and potentials associated with all seabed resources, (and in this case the Offshore Hydrocarbons sector) consistent with the MI remit.

K.Robinson (KR) stated that as far as PAD were concerned hydrocarbon resources (HCr's) were entirely within the bailiwick of the PAD and Enterprise Ireland and that they (HCr's) had been subject of agreed departmental documentation that set out the general roles of the
respective parties in this regard. More specific and detailed matters pertaining to the (HCr's) sector had been dealt with through occasional ad-hoc group meetings, attended by members of PAD, Enterprise Ireland and the MI the respectively. Unfortunately this group had not met in the past year.

Additionally KR stated that PAD regarded HCr's as an "earth resource" a concept in which the sea or marine environment merely intervened between the resource and it's extractor.

G.S. Described the methodology as set out in the CRC tender document, which in essence comprises a gap analysis between the requirements of the offshore hydrocarbons sector and the services and goods currently available through Irish operators. Also that there were many areas of potential research that could not be readily assigned to one of the existing domains, e.g., palynological studies, soil-sample analyses, biological benthic sampling, other acoustic technologies sonar, bathymetry, and various meteorological and oceanographic, hard, and software developments.

K.R. Replied stating that this methodology is precisely that currently being employed by Enterprise Ireland who are themselves engaged in an almost identical procedure directly on behalf of the DOMNR. Advised that GS should contact Neil Kerrigan and/or Ger Keane where 75% of the required material required for the MI project should be available.

In addition KR went on to describe the current operational status of the hydrocarbons industry operators in Ireland, working through the list of current licensees as per PAD document "Petroleum Exploration and Development Offshore Ireland, Acreage Position on 1st August 1999".

In this way a number of individuals and operators were highlighted (See List Attached) as being the most appropriate for further contact being in a potential position to provide information on their respective RTDI requirements.

Further advice was given with regard to the status of the hydrocarbons industry in general and those operating in the Irish sector in particular. It was suggested that many of the operators on the list would be less appropriate for further contact, a variety of very cogent reasons being cited. In overview KR advised that a wide view be taken of the hydrocarbons sector on an international basis in terms of establishing the research potential for Irish organisations. That the maximum opportunities in the field were not necessarily associated with the extant Irish resource, and some organisations such as IFP in France, and British Gas had enormous experience in the area of research.

GS. Replied stating that that may well be the case, and that these organisations would be contacted but that the study had heretofore been interpreted as focusing on exploitation of niche areas for research within the Irish geographical domain.

YS. Stated that the wider geographical approach would be beneficial provided that it retained sufficient focus to be of use in an Irish context. Also that there may be significant opportunities for organisations to operate at an international level.

GS. Pointed out that whilst this was possible in a number of areas, some e.g. the international seismic surveying industry required enormous capitalisation. However these areas would be explored as part of the study.
Appendix IV

KR. Agreed that there were likely to be a number of niche areas with research potential and that these were largely being addressed through the PIP (Petroleum Infrastructure Program) the current round of which was presently being processed by Noel Murphy of PAD.

GS. Asked if it would be possible to obtain details of the PIP program in order to document the topics and research areas covered, and identify further potential.

KR Advised referral to Noel Murphy. PAD

GS. Asked about the potential impact in Ireland of the recent European court decision handed down to the UK government with respect to it's application of the EU habitat directive out to the 200 mile limit.

KR replied that he had heard of the case but was currently unaware as to the likelihood of any impact in the Irish domain. Asked PR if he had any details of same.

GS Asked if PR could forward details should they become available since an increase in the level of EIA requirements, may have relevance to research applications associated with this field in which several Irish groups already have projects.

End of proceedings.

Table of suggested licensee contacts.

<table>
<thead>
<tr>
<th>Name of Operator</th>
<th>Contact person</th>
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<tbody>
<tr>
<td>Enterprise Oil</td>
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<tr>
<td>Chevron U.K.Ltd.</td>
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<tr>
<td>Marathon International Petroleum Ltd.</td>
<td>Dennis Twomey</td>
</tr>
<tr>
<td>Statoil Exploration (Ireland) Ltd</td>
<td>Ger Haar</td>
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<tr>
<td>Total Oil Marine plc.</td>
<td>Tony Macateer</td>
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<td>BG Exploration &amp; Production Ltd.</td>
<td>Peter Haines</td>
</tr>
<tr>
<td>Elf Petroleum Ireland BV</td>
<td>Fergus Cahill</td>
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<tr>
<td>Agip Ireland bv</td>
<td>Ron Landsdale</td>
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</table>

Table of other relevant contacts.

<table>
<thead>
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<th>Contact</th>
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<tr>
<td>Herriot-Watt University</td>
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<tr>
<td>Enterprise Ireland</td>
<td>Neil Kerrigan/ Ger Keane</td>
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<tr>
<td>International Association of Geophysical Contractors</td>
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Appendix V

Rockall PIP Summary of Approved Projects (As of 07/07/99. List provided by RSG secretariat)

(See next page)
## Appendix V Irish Rockall PIP Group 2: Summary of Approved Projects

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<thead>
<tr>
<th>Committee (mentor)</th>
<th>Description</th>
<th>Proposer</th>
<th>Email</th>
<th>Organisation</th>
<th>Web site</th>
<th>Project No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETC (AM)</td>
<td>Environmental data gathering and preliminary assessment</td>
<td>Martin Davies, Andy Wheeler, Jonathan Guard</td>
<td><a href="mailto:mdavies@csa.ie">mdavies@csa.ie</a>, <a href="mailto:a.wheeler@ucc.ie">a.wheeler@ucc.ie</a>, <a href="mailto:guard@csa.ie">guard@csa.ie</a></td>
<td>CSAOG, CRC, U.C. Cork</td>
<td><a href="http://www.ucc.ie/ucc/research/crc/">www.ucc.ie/ucc/research/crc/</a></td>
<td>97/52</td>
</tr>
<tr>
<td>ETC (AM)</td>
<td>TERM: TOBI Eastern Rockall Margin Acquisition contract</td>
<td>Neil Kenyon, Marieke Rietveld</td>
<td><a href="mailto:n.kenyon@soc.soton.ac.uk">n.kenyon@soc.soton.ac.uk</a>, <a href="mailto:rietveld@nioz.nl">rietveld@nioz.nl</a></td>
<td>Southampton Ocean. Centre, NIOZ (vessel)</td>
<td><a href="http://www.soc.soton.ac.uk">www.soc.soton.ac.uk</a>, <a href="http://www.nioz.nl/">www.nioz.nl/</a></td>
<td>97/14</td>
</tr>
<tr>
<td>ETC (AM)</td>
<td>TERM: TOBI Eastern Rockall Margin Processing &amp; Interpretation contract</td>
<td>Pat Shannon, Brian Jacob, Dave Naylor, Neil Kenyon</td>
<td><a href="mailto:p.shannon@ucd.ie">p.shannon@ucd.ie</a>, <a href="mailto:bj@cp.dias.ie">bj@cp.dias.ie</a>, <a href="mailto:info@era.ie">info@era.ie</a>, <a href="mailto:n.kenyon@soc.soton.ac.uk">n.kenyon@soc.soton.ac.uk</a></td>
<td>U.C. Dublin, DIAS, ERA-Maptec Ltd., Southampton Ocean. Centre</td>
<td><a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a>, <a href="http://www.geophysics.dias.ie">www.geophysics.dias.ie</a>, <a href="http://www.era.ie/ERA-Maptec/">www.era.ie/ERA-Maptec/</a>, <a href="http://www.soc.soton.ac.uk">www.soc.soton.ac.uk</a></td>
<td>97/14a</td>
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<tr>
<td>ETC (AM)</td>
<td>TERM: TOBI Eastern Rockall Margin QC work by Quentin Huggett</td>
<td>Quentin Huggett</td>
<td><a href="mailto:Huggett@GEOTEK.co.uk">Huggett@GEOTEK.co.uk</a></td>
<td>GEOTEK Ltd</td>
<td><a href="http://www.geotek.dircon.co.uk">www.geotek.dircon.co.uk</a></td>
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<tr>
<td>ETC (AM)</td>
<td>Cetacean and Seabird Monitoring in the Rockall Trough area</td>
<td>Emer Rogan, Mark Tasker, Simon Berrow</td>
<td><a href="mailto:e.rogan@ucc.ie">e.rogan@ucc.ie</a>, <a href="mailto:tasker_m@jncc.gov.uk">tasker_m@jncc.gov.uk</a></td>
<td>NUI Cork, JNCC, NUI Cork</td>
<td><a href="http://www.ucc.ie/ucc/research/crc/">www.ucc.ie/ucc/research/crc/</a>, <a href="http://www.jncc.gov.uk">www.jncc.gov.uk</a>, <a href="http://www.ucc.ie/ucc/research/crc/">www.ucc.ie/ucc/research/crc/</a></td>
<td>98/6</td>
</tr>
<tr>
<td>MC (PH)</td>
<td>Technical Review of Proposed Database Application</td>
<td>Jonathan Guard, John Wallace</td>
<td><a href="mailto:jguard@csa.ie">jguard@csa.ie</a>, <a href="mailto:j.wallace@informatic.ie">j.wallace@informatic.ie</a></td>
<td>CSAC, Informatic Management Internl</td>
<td><a href="http://www.informatic.ie">www.informatic.ie</a></td>
<td>98/18</td>
</tr>
<tr>
<td>MC</td>
<td>RSG Website development and maintenance</td>
<td>Kevin Lowe</td>
<td><a href="mailto:klowe@solomon.ie">klowe@solomon.ie</a></td>
<td>Solomon Solutions Ltd</td>
<td><a href="http://www.solomon.ie">www.solomon.ie</a></td>
<td>98/22</td>
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<tr>
<td>MTC (IL)</td>
<td>A MetOcean Strategy for the Rockall Area (incl. data compilation and review)</td>
<td>Bronwyn Cahill, Martin White, Ian Leggett</td>
<td><a href="mailto:bronwyn.cahill@marine.ie">bronwyn.cahill@marine.ie</a>, <a href="mailto:i.m.leggett@openmail1.uesc9.sukepa.be">i.m.leggett@openmail1.uesc9.sukepa.be</a>, simis.com</td>
<td>Irish Marine Data Center, N.U.I. Galway, Oceanography, Shell Expro Metocean Services</td>
<td><a href="http://www.marine.ie">www.marine.ie</a>, <a href="http://www.ucg.ie">www.ucg.ie</a></td>
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</tr>
<tr>
<td>SSTC (CN)</td>
<td>Structural elements nomenclature</td>
<td>David Naylor, Pat Shannon</td>
<td><a href="mailto:info@era.ie">info@era.ie</a>, <a href="mailto:p.shannon@ucd.ie">p.shannon@ucd.ie</a></td>
<td>ERA-Maptec Ltd., U.C. Dublin</td>
<td><a href="http://www.era.ie/ERA-Maptec/">www.era.ie/ERA-Maptec/</a>, <a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a></td>
<td>97/3</td>
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<td>SSTC (AS)</td>
<td>Gravity and magnetic studies and 2D/3D interpretation in the Irish RT</td>
<td>Mick Lee, Richard Carruthers, Andy McGrandle</td>
<td><a href="mailto:m.lee@bgs.ac.uk">m.lee@bgs.ac.uk</a>, <a href="mailto:r.carruthers@bgs.ac.uk">r.carruthers@bgs.ac.uk</a>, <a href="mailto:andy.macgrandle@arkgeo.demon.co.uk">andy.macgrandle@arkgeo.demon.co.uk</a></td>
<td>British Geological Survey, British Geological Survey, ARK Geophysics Ltd.</td>
<td><a href="http://www.bgs.ac.uk">www.bgs.ac.uk</a>, <a href="http://www.bgs.ac.uk">www.bgs.ac.uk</a>, <a href="http://www.arkgeo.com">www.arkgeo.com</a></td>
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<td>SSTC (PB)</td>
<td>Imaging through high impedance heterogeneous layers: Finite difference wave simulations</td>
<td>Chris Bean, Francesca Martini</td>
<td><a href="mailto:chris.bean@ucd.ie">chris.bean@ucd.ie</a>, <a href="mailto:francesca.martini@ucd.ie">francesca.martini@ucd.ie</a></td>
<td>U.C. Dublin, U.C. Dublin</td>
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<tr>
<td>SSTC (PB)</td>
<td>Gravity and magnetic studies</td>
<td>Andrew Brock, Eve Daly</td>
<td><a href="mailto:colin.brown@nuigalway.ie">colin.brown@nuigalway.ie</a>, <a href="mailto:eve.daly@nuigalway.ie">eve.daly@nuigalway.ie</a></td>
<td>U.C. Galway, Apl Geophys, N.U.I. Galway</td>
<td><a href="http://www.ucg.ie">www.ucg.ie</a></td>
<td>97/40</td>
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<tr>
<td>SSTC (CN)</td>
<td>Crystalline basement of the Rockall Trough</td>
<td>Stephen Daly, Ray Scanlon</td>
<td><a href="mailto:s.daly@macollamh.ucd.ie">s.daly@macollamh.ucd.ie</a>, <a href="mailto:rscanlon@macollamh.ucd.ie">rscanlon@macollamh.ucd.ie</a></td>
<td>U.C. Dublin, U.C. Dublin, University of Amsterdam</td>
<td><a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a></td>
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<tr>
<td>SSTC (AS)</td>
<td>RAPIDS 3 (Deep seismic) - Celtic Voyager charter, processing &amp; interpretation</td>
<td>Pat Shannon, Brian Jacob, Jannis Makris, Michael Gillooly</td>
<td><a href="mailto:p.shannon@ucd.ie">p.shannon@ucd.ie</a>, <a href="mailto:bj@cp.dias.ie">bj@cp.dias.ie</a>, <a href="mailto:jannis.makris@ham.de">jannis.makris@ham.de</a>, <a href="mailto:rv@marine.ie">rv@marine.ie</a></td>
<td>U.C. Dublin, DIAS, University of Hamburg, Irish Marine Institute (boat)</td>
<td><a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a>, <a href="http://www.geophysics.dias.ie">www.geophysics.dias.ie</a>, <a href="http://www.ifm.uni-hamburg.de/">www.ifm.uni-hamburg.de/</a>, <a href="http://www.marine.ie/frc">www.marine.ie/frc</a></td>
<td>97/11</td>
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<tr>
<td>SSTC (CK)</td>
<td>Vessel HSE audits</td>
<td>Rod Thonger, Neil Cave</td>
<td><a href="mailto:ukoffice@gsr-hse.com">ukoffice@gsr-hse.com</a></td>
<td>Thonger Safety Associates, Thonger Safety Associates</td>
<td><a href="http://www.gsr-hse.com">www.gsr-hse.com</a></td>
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<tr>
<td>SSTC (AS)</td>
<td>RAPIDS 3 (Deep seismic) - Boris Petrov charter, project management, cruise report</td>
<td>Frank Egloff, Brian Jacob, Jannis Makris</td>
<td><a href="mailto:fe@geopro.com">fe@geopro.com</a>, <a href="mailto:p.shannon@ucd.ie">p.shannon@ucd.ie</a>, <a href="mailto:bj@cp.dias.ie">bj@cp.dias.ie</a>, <a href="mailto:jannis.makris@ham.de">jannis.makris@ham.de</a></td>
<td>GeoPro GmbH, U.C. Dublin, DIAS, University of Hamburg</td>
<td><a href="http://www.geopro.com">www.geopro.com</a>, <a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a>, <a href="http://www.geophysics.dias.ie">www.geophysics.dias.ie</a>, <a href="http://www.ifm.uni-hamburg.de/">www.ifm.uni-hamburg.de/</a></td>
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<tr>
<td>STC (JC)</td>
<td>Seabed data gathering and preliminary assessment</td>
<td>Martin Davies, Pat Shannon, Andy Wheeler, Jonathan Guard</td>
<td><a href="mailto:mdavies@csa.ie">mdavies@csa.ie</a>, <a href="mailto:p.shannon@ucd.ie">p.shannon@ucd.ie</a>, <a href="mailto:a.wheeler@ucc.ie">a.wheeler@ucc.ie</a>, <a href="mailto:jguard@csa.ie">jguard@csa.ie</a></td>
<td>CSAOG, U.C. Dublin, CRC, U.C. Cork, CSAC</td>
<td><a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a>, <a href="http://www.ucce.ie/ucc/research/crc/">www.ucce.ie/ucc/research/crc/</a></td>
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<td>STC ETC (AJ/AM)</td>
<td>TTR 7 cruise: licence to RSG and data collation</td>
<td>Neil Kenyon, Michael Ivanov, Pat Shannon</td>
<td><a href="mailto:n.kenyon@soc.soton.ac.uk">n.kenyon@soc.soton.ac.uk</a>, <a href="mailto:fa@geo1.msu.ru">fa@geo1.msu.ru</a>, <a href="mailto:p.shannon@ucd.ie">p.shannon@ucd.ie</a></td>
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<td><a href="http://www.soc.soton.ac.uk">www.soc.soton.ac.uk</a>, <a href="http://www.unesco.org/ioc/tema">www.unesco.org/ioc/tema</a>, <a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a></td>
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<tr>
<td>STC (JC/AJ)</td>
<td>Atlantic Margin Drilling</td>
<td>Nigel Fannin, Ken Hitchen</td>
<td><a href="mailto:n.fannin@bgs.ac.uk">n.fannin@bgs.ac.uk</a>, <a href="mailto:k.hitchen@bgs.ac.uk">k.hitchen@bgs.ac.uk</a></td>
<td>British Geological Survey, British Geological Survey</td>
<td><a href="http://www.bgs.ac.uk">www.bgs.ac.uk</a></td>
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<td>STC (JP)</td>
<td>Onboard Micropalaeontology</td>
<td>Jake Jacovides</td>
<td><a href="mailto:jj@millemni.demon.co.uk">jj@millemni.demon.co.uk</a></td>
<td>Millenium Ltd</td>
<td></td>
<td>97/50a</td>
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<tr>
<td>STC (AJ)</td>
<td>Secure Web Server and comms link</td>
<td>Jon Curtis, Robert Bruce</td>
<td><a href="mailto:jon.curtis@petrolink.net">jon.curtis@petrolink.net</a></td>
<td>Petrolink Ltd</td>
<td><a href="http://www.petrolink.net">www.petrolink.net</a></td>
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<tr>
<td>STC (SC)</td>
<td>Sedimentological analysis of deep borehole cores, Rockall margin</td>
<td>Peter Haughton</td>
<td><a href="mailto:haughton@macollamh.ucd.ie">haughton@macollamh.ucd.ie</a></td>
<td>U.C. Dublin</td>
<td><a href="http://www.ucd.ie/~geology/home.html">www.ucd.ie/~geology/home.html</a></td>
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<tr>
<td>STC</td>
<td>Fluid Inclusion studies of deep</td>
<td>Martin Feely</td>
<td><a href="mailto:martin.feely@nuigalway.ie">martin.feely@nuigalway.ie</a></td>
<td>N.U.I. Galway</td>
<td><a href="http://www.ucg.ie">www.ucg.ie</a></td>
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<tr>
<td>(SC)</td>
<td>borehole cores</td>
<td>John Parnell</td>
<td><a href="mailto:j.parnell@abdn.ac.uk">j.parnell@abdn.ac.uk</a></td>
<td>University of Aberdeen</td>
<td><a href="http://www.abdn.ac.uk/geology">www.abdn.ac.uk/geology</a></td>
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<tr>
<td>(JP)</td>
<td>High resolution Biostratigraphy at the margins of Rockall Trough</td>
<td>Ken Higgs</td>
<td><a href="mailto:k.higgs@ucc.ie">k.higgs@ucc.ie</a></td>
<td>N.U.I. Cork</td>
<td><a href="http://www.ucc.ie/ucc/research">www.ucc.ie/ucc/research</a></td>
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<td>(CK)</td>
<td>Geotechnical sample analysis (linked to 97/50)</td>
<td>Tim Paul</td>
<td><a href="mailto:tpaul@csa.ie">tpaul@csa.ie</a></td>
<td>John Barnett Associates</td>
<td><a href="http://www.tcd.ie/Engineering/index.html">www.tcd.ie/Engineering/index.html</a></td>
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<tr>
<td>(SC)</td>
<td>Geochemical sample analysis (linked to 97/50)</td>
<td>Malvin Bjoroy</td>
<td><a href="mailto:firmapost@geolab-nor.telemax.no">firmapost@geolab-nor.telemax.no</a></td>
<td>Geolab Nor AS, Trondheim</td>
<td><a href="http://www.maxware.no/Norsklab/geolab.html">www.maxware.no/Norsklab/geolab.html</a></td>
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Appendix VI

List of statutory instruments of the Health and Safety Authority
Associated with Offshore Oil and Gas in Ireland

The Acts, Orders, Regulations and Codes of Practice, etc. listed here are obtainable from the Government Publications Sales Office.

Regulations made under Safety, Health and Welfare at Work Act, 1989

1989
Safety, Health and Welfare at Work Act, 1989 (Commencement) Order, No. 236
Safety, Health and Welfare at Work Act, 1989 (Repeals) Order, No. 237
District Court (Safety, Health and Welfare at Work Act, 1989) Regulations, No. 275

1990
Safety, Health and Welfare at Work Act, 1989 (Repeals) Order, No. 103

1991
Safety, Health and Welfare at Work, 1989 (Control of Specific Substances and Activities) Regulations, No. 285

1993
Safety, Health and Welfare at Work (General Application) Regulations, 1993 No. 44
Safety, Health and Welfare at Work (Carcinogens) Regulations, No. 80

1994
Safety, Health and Welfare at Work (Biological Agents) Regulations, No. 146
Safety, Health and Welfare at Work (Chemical Agents) Regulations, 1994 (see Approved Code of Practice) No. 445
Safety, Health and Welfare at Work (Pregnant Employees etc) No. 446

1995
Safety, Health and Welfare at Work (Signs) Regulations, No. 132
Safety, Health and Welfare at Work (Construction) Regulations, No. 138
Safety, Health and Welfare at Work (Repeals and Revocations) Order, No. 357

Regulations made under European Communities Act, 1972

1979 European Communities (Wire Ropes, Chains and Hooks) Regulations, S.I. No. 207
1981 European Communities (Electrical Equipment for Use in Potentially Explosive Atmospheres) Regulations, S.I. No. 61

1986 European Communities (Electrical Equipment for Use in Potentially Explosive Atmospheres) (Amendment) Regulations, S.I. No. 244
European Communities (Major Accident Hazards of Certain Industrial Activities) Regulations, S.I. No. 292

1988 European Communities (Protection of Workers) (Exposure to Lead) Regulations, S.I. No. 219

1989 European Communities (Protection of Workers) (Exposure to Asbestos) Regulations, S.I. No. 34

European Communities (Major Accident Hazards of Certain Industrial Activities) (Amendment) Regulations, S.I. No. 194

European Communities (Protection of Workers) (Exposure to Chemical, Physical and Biological Agents) Regulations, S.I. No. 251
1990 European Communities (Protection of Workers) (Exposure to Noise) Regulations, S.I. No. 157

1991 European Communities (Electrical Equipment for Use in Potentially Explosive Atmospheres) (Amendment) Regulations, S.I. No.289

1992 European Communities (Major Accident Hazards of Certain Industrial Activities) (Amendment) Regulations, S.I. No. 21

1993 European Communities (Protection of Workers) (Exposure to Asbestos) (Amendment) Regulations, S.I. No. 276

1994 European Communities (Classification, Packaging, Labelling and Notification of Dangerous Substances) Regulations, S.I. No. 77
European Communities (Dangerous Substances and Preparations) (Marketing and Use) Regulations,

1994 S.I. No. 79

1995 European Communities (Classification, Packaging and Labelling of Dangerous Preparations) Regulations, 1995 S.I. No. 272

**Regulations made under Mines and Quarries Act, 1965**

Mines (Managers and Officials) Regulations, 1970 (part of Reg. 29(3) REVOKEDE) S.I. No. 74
Mines and Quarries (Reference) Rules, 1970 S.I. No. 75
Appendix VI

Mines and Quarries (Notification of Dangerous Occurrences) Order, 1970 S.I. No. 76
Mines (Surveyors and Plans) Regulations, 1970 S.I. No. 78
Mines and Quarries (Birth Certificates) Regulations, 1970 S.I. No. 110

Mines and Quarries Inquiries (Draft Regulations) Rules, 1971, S.I. No. 219
Quarries (Explosives) Regulations, 1971 Reg. 52(2) REVOKED, S.I. No. 237
Mines (Locomotive) Regulations, 1971, S.I. No. 238

1972 Quarries (Electricity) Regulations, 1972, S.I. No. 50
Mines (Electricity) Regulations, 1972, S.I. No. 51
Mines (Explosives) Regulations, 1972, S.I. No. 123
Mines (Fire and Rescue) Regulations, 1972 (Parts of Reg. 25(c), 28(1)(a), 28(1)(c), 28(1)(e) nad 37(2)(a) partly REVOKED and the second schedule REVOKED) S.I. No. 226


1974 Mines and Quarries (General Register) Regulations, 1974, S.I. No. 97
Quarries (General) Regulations, 1974, (Reg. 19(2), 19(3), 28,32, 34-36 REVOKED), S.I. No. 146

1975 Mines (General) Regulations, 1975 (Reg. 31,60,67,70-72 REVOKED) S.I. No. 331

1976 Quarries (Explosives) (Amendment) Regulations, 1976 S.I. No. 1


1979 Mines (Electricity) (Amendment) Regulations, 1979, S.I. No. 125
Quarries (Electricity) (Amendment) Regulations, 1979, S.I. No. 126
Mines (General) (Amendment) Regulations, 1979, S.I. No. 279

1987 Quarries (Safety Training) Regulations, 1987, S.I. No. 85

No. 153 of 1991

Regulations made under Dangerous Substances Acts, 1972 and 1979

1979 Dangerous Substances Act, 1972 (Commencement) Order, 1979, S.I. No. 297
Dangerous Substances Act, 1972 (Licensing Fees) Regulations, 1979, S.I. No. 301
Dangerous Substances Act, 1972 (Retail and Private Petroleum Stores) Regulations, 1979, S.I. No. 311
Dangerous Substances Act, 1972 (Oil Jetties) Regulations, 1979, S.I. No. 312
Dangerous Substances Act, 1972 (Petroleum Bulk Stores) Regulations, 1979, S.I. No. 313 (Reg.45(1) partly REVOKED and Reg.79 and schedule 6 REVOKED)
Appendix VI

Dangerous Substances Act, 1972 (Conveyance of Petroleum by Road) Regulations, 1979, S.I. No. 314

1980 Dangerous Substances Act, 1972 (Conveyance of Scheduled Substances by Road) (Trade or Business) Regulations, 1980 (and approved Code of Practice - see Part C), S.I. No. 235 (Reg. 20 REVOKED)

1986 Dangerous Substances Act, 1972 (Conveyance of Scheduled Substances by Road) (Trade or Business) (Amendment) Regulations, 1986 (and approved Code of Practice S.I. No. 268)

Dangerous Substances (Retail and Private Petroleum Stores) (Amendment) Regulations, 1988, S.I. No. 303

1990 Dangerous Substances (Storage of Liquefied Petroleum Gas) Regulations, 1990 (see Approved Codes of Practice), S.I. No. 201

Dangerous Substances (European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR)) Regulations, 1996 (S.I. No. 388 of 1996)
Dangerous Substances (Conveyance of Scheduled Substances by Road (Trade or Business) (Amendment) Regulations, 1996 (S.I. No. 389 of 1996)

Miscellaneous Regulations and Orders

1992 European Communities (Machinery) Regulations, 1992
S.I. No. 246

1993 Labour (Transfer of Departmental Administration and Ministerial Functions) Order, 1993
S.I. No. 18

1993 Industry and Commerce (Alteration of Name of Department and Title of Minister) Order, 1993
S.I. No. 19

1995 Enterprise and Employment (Delegation of Ministerial Functions) (No. 2) Order, 1995
S.I. No. 43

Approved Codes of Practice

Appendix VI

The following is approved as a Code of Practice:

Sections 2, 3, 4 and 6 of the UK Liquefied Petroleum Gas Industry Technical Association Code of Practice 2 of January, 1974 in respect of tanks used for the conveyance by road of propane, butane and mixtures of both, subject to certain specified conditions being met relating to the design, construction, testing, examination and marking of tanks.


The following standards published by the National Standards Authority of Ireland (N.S.A.I.) are approved as Codes of Practice:

- Code of Practice for the storage of LPG Cylinders and Cartridges I.S. 3213: 1987 as amended by Amendment No.1 : 1990, dated 20th September, 1990 and by Amendment No. 2 : 1993, dated 22nd September, 1993; and

Appendix VII

Underwater Robotics - Current Applications

Introduction
Traditionally, in the realms of both science and engineering, divers performed the majority of subsea intervention. Whether the task was the collection of samples or subsea construction, the activities largely mirrored their surface equivalents. Today, particularly in areas such as marine drilling, there is considerable use of very sophisticated remote control, but this is not robotics, in the sense of the replication of human-like activity. The principal application of robotics in current underwater activity, both engineering and scientific, is the tethered but free-swimming Remotely Operated Vehicle - the ROV.

A Bit of History
The ROV first established a track record for robotic intervention in the 1960s, off the coast of Spain, when used in the search for, and retrieval of, the lost H-bomb. This vehicle was very rudimentary - little more than a couple of thrusters and a basic manipulator in a frame (work class ROVs are sometimes referred to as 'open-frame' ROVs). Shortly thereafter, another ROV was used in the successful rescue of a manned submersible, an event that was seen as demonstrating the supremacy of the ROV over manned intervention. It is possible to say that development of the work class ROV never looked back, although its development has been far from meteoric. Indeed, apart from developments in on-board diagnostics, it has been suggested that the ROV has not advanced over the past ten years.

Eyeball ROVs
Some small ROVs carry only a camera (and possibly a sonar) and, as such, can do no manipulative work, although they can, to a limited extent, provide 'telepresence' - the feeling by the observers that they are at the site. For this reason, such ROVs are generically known as 'eyeball' ROVs. Eyeball ROVs were often used to monitor divers at work. Initially, the divers resented their intrusion and saw them as the thin end of the wedge of their own eventual replacement. With time, they became more comfortable with the knowledge that their safety could be better monitored. Now, there are fewer divers, and many more ROVs. At this time, telepresence by ROV is limited by the two-dimensional nature of underwater cameras, but methods are currently being perfected to provide awareness of depth, by stereo viewing techniques and by combining visual and sonar data.

The Work Class ROV
Today's typical 'work class' ROV for the offshore industry consists of a frame which supports the hydraulic pumps, the thrusters, all ancillary equipment (cameras, sonars, etc) and the electronic control equipment, the mass of which is distributed to achieve balance and whose submerged weight is compensated by syntactic foam buoyancy fitted to the upper part of the frame to achieve neutral buoyancy. It will be fitted with a five-function grabber arm, used to hold the ROV steadily in one position, and a seven-function manipulator, which is then used to perform robotic tasks. The manipulator will be a derivation of those found in various industrial applications.
ashore, having a number of joints, a rotating wrist, and a hand-like claw. For some applications, the ROV will be equipped with a special tooling skid designed to locate and lock on to a docking panel whence various valves and controls can be activated. The ROV is now used for many tasks in the offshore theatre: drilling support, site survey, debris clearance, structure cleaning and inspection, flowline and umbilical tie-in, pipeline inspection, route survey, or override of operational functions. However, the offshore industry is by no means the only place where work class ROVs are to be found. They have a significant part to play in mine countermeasures, both for surveying routes, and for locate and destroy missions when a suspicious object is identified. They are also used for civil engineering work, such as inspection and maintenance of dams, docks, hydroelectric installations and sewer outfalls, and cleaning the hulls of ships without dry-docking. While some of the ROVs are rather smaller, another important sector is scientific exploration and marine archaeology (e.g. arresting pictures from the Titanic).

However, it is interesting to consider that the ROV itself has never really been seen as a robotic entity but more of a delivery system for robotic intervention tools. Evidence for this view is the maintenance of the open frame, to the detriment of hydrodynamic performance, in order that different tools can be added and removed with ease. Of course, in the early days, this was partly a reflection of the poor reliability of many underwater tools, but there was also a view that mission payloads had to flexible. But nothing has really changed and the result tends to be that various cameras and tools are clamped to the frame, their individual submerged weights being compensated for by odd bits of additional buoyancy, until the operational vehicle resembles a covered wagon of the old 'wild west' with all its accoutrements hanging around the periphery. The modern approach is to design tool skids that fit either to the front, or to the underside, of a number of the industry's most common vehicles so as to maintain flexibility. The vehicles still retain the open-frame design, however, and the poor hydrodynamics are exacerbated by the addition of these tool skids. To this day, some of the most notable achievements by ROVs have been achieved with the most incredibly ungainly units.

It might be assumed that, to achieve tasks of human dexterity, the tools would become more like arms and hands, whereas, to deliver tools and provide a stable working platform subsea, the vehicles might become more like marine mammals. The former is happening, although there is a recognition that, if humans are not to perform the tasks anyway, there may be better ways of designing the systems to be manipulated than to replicate human methods; but the vehicles themselves are not at all adapted to their environment. It is only fair to point out that there were one or two attempts to design integrated robotic units with hydrodynamically efficient hulls (such as the MMIM - marine maintenance and inspection machine) but these never caught on and, after all, the customer is always right.

Other ROVs
There are other types of remotely operated vehicle which carry out subsea tasks at the end of some form of umbilical, such as crawler vehicles of varying size which can trench and bury pipelines or umbilical and power cables, or which perform seabed excavation, and machines which crawl up and down mooring wires or tension legs to perform inspection, but these are not really 'robotic' in the sense of replicating human activity. There are also Remotely Operated Towed Vehicles (ROTVs) which carry side-scan sonar for route and pipeline survey; they have no motive power, but can be remotely controlled to move laterally and vertically with considerable precision. Again, these are not really robotic. However, the next phase in the development of the
ROV is the Autonomous Underwater Vehicle (AUV), and these will replicate human activity not only in their manipulative dexterity, but also in their ability to 'think'.

The Requirement for Underwater Inspection Robots in the Offshore Oil and Gas Industry
Initiatives to maximise safety and reduce costs are leading to the phasing out, as far as possible, of manned diving operations in the North Sea. There are now several robotic systems under development and in use which can replace the divers who inspect offshore platforms. There are over 400 offshore oil and gas production platforms in the North Sea and about 6000 world-wide. Most of these are welded steel tubular structures and some of them have now been in service for over twenty years. Techniques that enhance oil production are now extending the economic life of oil fields, sometimes beyond the original design lives of the platforms. Fatigue cracks can develop in welded joints and underwater inspection is an important part of ensuring continued safe operation. Robots have now been developed to perform the following types of task previously done by divers:

- Cleaning marine growth from welds
- Weld inspection using techniques such as Magnetic Particle Inspection or Eddy Current testing
- Current measurement from sacrificial anodes
- Wall thickness measurements on steel tubulars

More information on weld testing is available from TWI (The Welding Institute at Cambridge, England)

Recently Developed Underwater Inspection Robots
The two robots mentioned here are delivered to the underwater work site by ROVs. Brief overviews of the ARM (automated remote manipulation) and REMO (remotely operated vehicle) systems are available below:

Topics for Further R&D
The following areas require further development if robots are to eventually completely replace divers for underwater inspection work.

- Robot arm deployed inspection sensors which can accurately measure crack depth on complex welded joints. (This would permit the requirement for repairs to be more readily assessed.)
- Operation of underwater inspection robots in zero visibility. (This is the subject of a new BRITE-EURAM project called VENICE. One of the partners is Omnitech who develop high-resolution sonar cameras).
- Repair techniques utilising underwater robots

The ARM System
Status
The ARM 2 Project has developed a new subsea system for the cleaning and inspection of nodal welds. It consists of an advanced robotic manipulator mounted on an extend/roll mechanism. This is part of a special toolskid carried by a standard workclass ROV. The manipulator was developed specially for inspection by Slingsby Engineering Limited. It is controlled by a unique, PC-based robot system developed by Technical Software Consultants Limited. This provides a full 3D graphical model of the ROV, toolskid, manipulator and workpiece node. It provides full manual, semi-automatic and robotic control of the manipulator (with collision detection).
The ARM 1 Project ended in September 1994 with the build of the new underwater manipulator and computer supervisory control system. The ARM 2 Project was completed in February 1996 with the build and factory testing of an entire inspection system consisting of the manipulator, an enhanced control system, a toolskid with a manipulator deployment system and attachment system, a compliant tracking system and an array based subsea NDT sensor. As before, this phase was sponsored by Mobil North Sea Ltd (MNSL) and the Oil and Gas Projects Supplies Office (OSO).

The ARM 3 Project recently trialled the complete ARM 2 system in the testing tank at the National Hyperbaric Centre in Aberdeen, Scotland, with great success. The complete ARM system was deployed on an 18 ton T-piece node. The complete ARM spread was due to go offshore in the summer of 1996 to inspect the Beryl Bravo platform for Mobil.

Description
The ARM system has several features which enable remote, automated subsea intervention to be carried out safely, efficiently and economically. In particular, its extend/rotate deployment boom gives unparalleled access to subsea structural components, far in excess of that achievable by any other unmanned inspection system. The planning and control of the equipment is accomplished with a graphical interface which brings the operator immediately into the work areas, enabling collision free motion of the ARM, the following of complex paths etc. The ARM system, designed for structural NDT inspection, also contains new compliant sensor and tool mountings that eliminate positional errors and enable accurate placement or tracking of probes. The heart of the system is the ARM manipulator. This is the largest commercially available subsea manipulator (at the time of writing), and by far the most dextrous. It has the following unique features: A reach of 2.5m and a lift capacity of approximately 150kg. The six joints are large hydraulic vane actuators allowing up to 270 degrees of rotation at each point. A new digital joint controller to implement full PID control rather than the proportional system used in most subsea arms. During manufacture calibration marks and assembly guide pins were added to ensure that the manipulator can be calibrated accurately, and recalibrated easily - an important requirement for a computer controlled robotic arm. All the subsea ARM equipment is mounted in a toolskid capable of being carried on any workclass "ROV of opportunity". This toolskid is a steel box frame structure mounting the following equipment:

- An extend/rotate deployment system. This consists of a box frame running down the centre of the toolskid and mounting the manipulator. It can be extended up to 2m in front of the toolskid, and it can rotate the manipulator shoulder through 360
Appendix VII

degrees. This allows the arm to reach into worksites that the ROV cannot access, and enables the arm to work as easily on its side or upside down.

- **Attachment legs.** These consist of hydraulic extending legs mounted on the toolskid and terminated with suction "sticky feet". Three arms are the minimum required for stable attachment, and they are usually arranged in a tripod for maximum rigidity. This requires one to be attached to the top front face of the ROV but a 'goalpost crossbar' is provided for this so no modification is required to the ROV. The sticky feet are unique, however, in that they can be attached anywhere on the toolskid as required. The usual configuration is for one on either side attached at the required height on the 'goalpost uprights' and the third on the crossbar as described. However, they can be attached wherever required for the job, including on the sides, rear and underneath of the toolskid.

- **Integral inspection equipment, valve packs, suction pumps, etc.** so that the only links required to the ROV, apart from the physical interface, are an umbilical communication and a hydraulic supply.

- **Pressure vessels for the manipulator controller, ACFM inspection system and Compliant Wrist unit.**

To make maximum use of the highly complex ARM system, it is computer controlled. The ARM supervisory controller comprises a fast PC surface graphics control unit linked via the Remotely Operated Vehicle (ROV) umbilical to a subsea arm controller. This provides full control of the manipulator, including manual master-slave tele-manipulation and fully automated, robotic task execution. A 3D video representation of the ROV, manipulator and work site is presented to the operator using solid shaded colour graphics, and can be used to monitor the arm whilst planning or executing tasks. The viewpoint can be modified to aid visualisation, and secondary windows used to display plan and elevation views of the arm and its work area. Also the arm can be viewed as if from an ROV mounted camera to give a close up which should correlate with actual television images. The arm can be controlled by a choice of input devices including keyboard, mouse, master arm or joysticks and operated in a variety of co-ordinate systems such as joint, world, tool, workpiece, etc. The system also includes simulation and collision detection of the boom deployment system and sticky feet attachment legs.

**Remotely Operated Vehicle (REMO)**

REMO (see figure below) is an ROV (Remotely Operated Vehicle)-based underwater
robot developed for cleaning and inspection of welds on complex steel joints.

The vehicle, with its tether management system (TMS), is deployed using a launch and recovery system (LARS). REMO then separates from the TMS and moves to the work site. The vehicle then attaches itself to the welded tubular intersection (or "node") by means of suction pads, for large tubulars, or with claws deployed on two six-function manipulators for tubulars of less than 10" diameter. Once rigid docking with the node has been achieved a video picture of the work site is frozen from one of the two environment acquisition video cameras. This image is then used to generate a 3D graphic model of the worksite, which can be used to simulate reach and access for the inspection and cleaning tools. The inspection can then be planned and programmed before the actual work starts. The appropriate tools are then selected for carrying out the cleaning inspection and deployed with a teleoperated manipulator. The work is monitored visually using cameras. REMO carries two different weld inspection tools for crack detection. These are Magnetic Particle Inspection (MPI) and Eddy Current Testing.

**REMO Project history**

The REMO system is owned and operated by Stolt Comex Seaway, one of the major offshore Inspection Maintenance and Repair (IMR) contractors. The project was started in 1990 with the support of two oil companies producing hydrocarbons from the Norwegian sector of the North Sea - Elf Petroleum Norge and Phillips Petroleum. In June 1995 REMO completed the inspection of a total of 30 subsea platform nodes in Phillips Petroleum's Ekofisk field. The capability of the system has recently been further enhanced by the development of a robotic grinding system for the removal of cracks in welds.

**Underwater Robotics- Future Applications**

**Introduction**

The application of underwater robotics today is largely represented by the work class Remotely Operated Vehicle (ROV). This type of vehicle performs a variety of tasks subsea, predominantly in the offshore oil and gas industry, but also in civil engineering and marine sciences. It is likely that the ROV will continue as a subsea intervention work horse for many years to come during which most developments, as noted below, are likely to be in their robotic systems. Meanwhile, there is likely to be an increasing role for the Autonomous Underwater Vehicle as it develops technically, and the following also looks at some of their potential applications.

**ROVs and Structures**

There are many large steel structures in the North Sea and the waters of the US Gulf, many of which are getting on in years. As a means of maintaining the cost-effectiveness of these assets, their operators are looking for new deposits to exploit by tying them back to these platforms (as mentioned previously). This requires that the integrity of the structures in terms of both corrosion and fatigue is assessed and guaranteed, probably beyond the original design life, and this will require extensive inspection. The detailed inspection of many hundreds of structural nodes, most of which will require cleaning first, is a massive task. It is only really cost effective if it can be automated, and this is likely to be a major application of ROVs in future. The vehicle technology will not have to improve greatly since they will probably continue to be launched near the site with an umbilical for power, but automation of the
applications will continue to advance. Systems are already in the development stage whereby the vehicle will fly to a general location, identify the node it seeks, lock on, learn the geometry, clean and inspect. This will require sophisticated robotic arms, measuring systems employing sonar or laser technology, and solid geometry modelling packages. The ROVs will also be task-programmed: in other words, there will not be a pilot at the controls continuously; the ROV will perform the work with only supervisory control.

Other ROV-based Subsea Tasks
The existing ROV technology is already employed for other construction tasks, such as subsea flowline pull-in and connection, or support for underwater cable burial and maintenance operations, as well as the associated survey work, with the former tasks seeing power levels on the vehicles reaching 200hp and beyond. It is also not unusual to see ROVs of 75-100hp being used in drilling support tasks. Drill-cutting removal using high-powered dredges is a common task in this area. ROVs are also deployed to operate subsea equipment which is not directly controlled from the surface (such as cross-over and isolation valves on trees and manifolds) although, in the latter case, parallel developments in through-water acoustic telemetry may bring much more subsea hardware under direct surface control. This same acoustic telemetry will be used for supervisory control of AUVs - discussed below. A major limitation to ROV development at present relates to onboard power. A great deal of research and development has been carried out looking for suitable Fuel Cell technology. However, there are currently no means of supplying the high power demands of work class ROVs (for the thrusters - to overcome the high hydrodynamic forces, and for tools, manipulators, etc) with cost-effective, self-contained packages small enough to be carried on board. Therefore, it is necessary for the power to be supplied via an umbilical cable; and since the cables have to be used for power, they are also used for control and video/data acquisition. The overall problem of the umbilical cable manifests itself in generating considerable hydrodynamic drag which requires considerable power (delivered via the umbilical itself) to be wasted counteracting it, thus creating a vicious circle. Improvements in enabling technologies will enhance the ROV in terms of its ability to perform difficult tasks in more remote areas. Similar problems occur with AUVs except that, in this case, an umbilical cannot be used and therefore the task portfolio must be constrained by the requirement for good hydrodynamic hull design. Currently, the power requirement of AUVs is satisfied, predominantly, by the use of lead-acid batteries, which provide relatively low power levels from relatively large and heavy units. Thus power technology is still fundamental.

AUVs in the Offshore Oil and Gas Industry
It follows from the above that Autonomous Underwater Vehicles (AUVs - those without umbilicals) are limited in their ability to perform many of the tasks associated with the offshore hydrocarbon industry which are heavy and dextrous. However, there are tasks which, while not urgently requiring AUV technology, will undoubtedly be performed in this manner once the techniques are proven. Such tasks include inspection of submarine pipelines and their associated systems to confirm integrity. Benefits will accrue from the ability to launch vehicles in narrow weather windows to deploy on major tasks unhampered by weather sensitivity. The UK Sector of the North Sea alone is host to some 8000 kilometres of pipeline, so this is no insignificant task. Similar payloads will be required to conduct route surveys prior to installation of pipelines and submarine cables and before tow-out of structures; once the cost-
effectiveness is proven the techniques will surely be used in many parts of the world, especially in deep water.

**Related Technology - Metoceanographical Research**

The ability to deploy AUVs to cruise over long distances without mother ship support has implications for the offshore industry as well as science. The oil companies are probing onto and beyond the European Continental Slope but this is a region whose oceanography is poorly understood. There is much scope for cruises to gather data on currents, seismic activity and seabed geotechnics. This will feed into the design of offshore installations, with particular regard to hydrodynamic loading on deep draught, surface-piercing structures, and the mooring systems they will require. These results, and others, will also be used by the scientific community to enhance knowledge of global climatology, and the geology of, for instance, the mid-ocean ridges and the associated plate tectonics. This is of great significance not only as a result of the magnitude of the cruises which can be considered if no mother ship is required, but also for research and exploration under the pack ice. Scientific investigation is likely to take AUVs to greater depths than will the offshore industry. In order to design vehicles which can carry sensor packages both to great depths and over long distances, it is necessary to consider the use of alternative materials for the pressure hull so as to maximise strength:weight ratio, and for the internal components to minimise weight. Once again, power is an important enabling technology, of course. Other important enabling technologies in this regard are those of navigation (especially inertial navigation systems) and collision avoidance (both the sensors and the logic). Long range acoustic telemetry is also important as a means both of receiving navigational updates, but also for supervisory control of the missions.

**Military Applications**

The same ability to range far and wide without close support is of value in surveillance applications such as mine countermeasures where AUVs can be dispatched on pre-determined tracks to look for objects which have appeared since the last cruise. It may be necessary to develop logic and control algorithms to enable the AUV to decide whether to break off from the given task for close investigation and report back before resuming the search pattern. This also has implications for the navigation systems.
Appendix VIII

Sources of data used for sand and gravel section(3).
Based on CRC sand and gravel database and GIS (see next page)
<table>
<thead>
<tr>
<th>Ref No</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>British Geological survey, SeaBed Sediments and Quaternary Geology, Isle Of Man Sheet.</td>
</tr>
<tr>
<td>2</td>
<td>British Geological survey, SeaBed Sediments and Quaternary Geology, Nymphbank Sheet.</td>
</tr>
<tr>
<td>3</td>
<td>Codling Bank Site Investigation.</td>
</tr>
<tr>
<td>8</td>
<td>Littoral and Benthic Investigations on the South Coast of Ireland -II. The Macrobenthic Fauna off Carnsore Point.</td>
</tr>
<tr>
<td>9</td>
<td>Cruise Report 93-303 Marine Geological Surveys in Dingle Bay, County Kerry, Southwest Ireland.</td>
</tr>
<tr>
<td>10</td>
<td>Environmental Impact Statement for a Proposal to Dredge Marine Aggregates From a Site South of Waterford Harbour.</td>
</tr>
<tr>
<td>11</td>
<td>The Sediments of Kilkieran Bay (Co. Galway Between Kilkieran and Dinish Shoals).</td>
</tr>
<tr>
<td>12</td>
<td>Benthic Macrofaunal Assemblages of Greater Galway Bay.</td>
</tr>
<tr>
<td>13</td>
<td>Benthic Studies off the West and South Coasts of Ireland. Published in Lough Beltra Cruise Reports 1984.</td>
</tr>
<tr>
<td>14</td>
<td>Duchas inventory of Irish shipwrecks.</td>
</tr>
<tr>
<td>15</td>
<td>Report on Site Investigation (1971) in Approaches and Channel of Lower Harbour Area, Cork, Republic of Ireland.</td>
</tr>
<tr>
<td>16</td>
<td>Ordnance Survey of Ireland Digital Discovery Series. Coastline Sheets.</td>
</tr>
<tr>
<td>17</td>
<td>Geological Survey of Ireland Seabed Samples (Geoman).</td>
</tr>
<tr>
<td>18</td>
<td>Duncannon Seabed Samples.</td>
</tr>
<tr>
<td>19</td>
<td>Duncannon Bar Site Investigation.</td>
</tr>
<tr>
<td>20</td>
<td>M1 / Fisheries Research Centre Herring Spawning Project.</td>
</tr>
<tr>
<td>21</td>
<td>Rosslare strand grab samples.</td>
</tr>
<tr>
<td>22</td>
<td>British Geological Survey Seabed Sample Metadata.</td>
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<td>Title</td>
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</tr>
<tr>
<td>33</td>
<td>The South West Irish Sea Survey (sediment data only).</td>
</tr>
<tr>
<td>34</td>
<td>MRM Sand and gravel project Bray bank to Kish bank geological survey.</td>
</tr>
<tr>
<td>36</td>
<td>Clew Bay Admiralty and IHD seabed sample descriptions.</td>
</tr>
<tr>
<td>37</td>
<td>Galway-Aran Islands RoxAnn data.</td>
</tr>
<tr>
<td>38</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 2/93. (Geoman cr1). South and East coasts.</td>
</tr>
<tr>
<td>39</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 2/89. (Geoman cr6). South and East coasts.</td>
</tr>
<tr>
<td>40</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 3/88. (Geoman cr9). East coasts.</td>
</tr>
<tr>
<td>41</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 2/88. (Geoman cr10). West coast.</td>
</tr>
<tr>
<td>42</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 1/87. (Geoman cr12). West coast Galway bay.</td>
</tr>
<tr>
<td>43</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 1/86. (Geoman cr13). West coast Galway bay.</td>
</tr>
<tr>
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<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 3/85. (Geoman cr ref 20; Beltra ref-25/85) East coast north Irish Sea.</td>
</tr>
<tr>
<td>45</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 2/86. (Geoman cr 13) South coast.</td>
</tr>
<tr>
<td>46</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 2/85. (Geoman cr 22; Beltra ref 15,16/85) West coast.</td>
</tr>
<tr>
<td>47</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 1/85. (Geoman cr 17; Beltra ref10/85) South coast.</td>
</tr>
<tr>
<td>48</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 4/84. (Geoman cr 25; Beltra cr ref 18/84) South east coast.</td>
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<td>49</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 1/84. (Geoman cr 23; Beltra cr ref 2/84) South coast.</td>
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<td>50</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 3/84. (Geoman cr 24) East coast.</td>
</tr>
<tr>
<td>51</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 2/84. (Geoman cr 19; Beltra cr ref 8/84) East coast. Kish bank Basin.</td>
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<td>52</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 5/84. (Geoman cr 15: Beltra ref 29/84) East coast.</td>
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<td>53</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 2/83. (Geoman cr 27) South West coast.</td>
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<td>54</td>
<td>Geological survey of Ireland marine geophysical reconnaissance cruise no 1/83. (Geoman cr 26) East coast.</td>
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<tr>
<td>59</td>
<td>Admiralty Bathymetry of Ireland</td>
</tr>
<tr>
<td>61</td>
<td>Lough Beltra cruise 28/06/94 to 03/04/94. (MI cr. Ref. 34) West Coast.</td>
</tr>
<tr>
<td>62</td>
<td>A preliminary report on the recent sedimentation on the sea floor immediately to the East of Dublin. RS 76/1 (Marine Geology).</td>
</tr>
</tbody>
</table>
Refusal of license to extract gravel in Dunmore East.

Clr. Geoff Power was informed in a phone-call from Frank Fahy TD minister for the Marine and Natural Resources, that he was refusing the application for a foreshore license to allow for the extraction of gravel from the spawning grounds of the Waterford coast.

"I am delighted with news as I am certain that if permission was given to remove sand and gravel it would have proved a disaster for the fishermen of this area. I believe that their livelihood is of the utmost importance and nothing should be done to interfere with that."

"I have been actively working on this for a number of years, both through Waterford County council and in any contact with the DOMNR. I feel it is a common sense decision, and shows that this minister is sympathetic to the plight of fishermen. I would also like to acknowledge the help of Brendan Kenneally with whom I have been working in this matter."
Appendix X

Draft Guidance on Environmental Impact Assessment in Relation to Dredging Applications in English Waters

Introduction

Marine sand and gravel extraction in English and Welsh waters will shortly be brought under statutory control with the introduction of the Environmental Impact Assessment and Habitats (Extraction of Minerals by Marine Dredging) Regulations 2000. These Regulations will transpose the requirements of the European Community Directives on Environmental Impact Assessment for certain public and private projects\(^3\) and on the conservation of natural habitats and of wild fauna and flora\(^4\) into national law in so far as they relate to the marine dredging of minerals around the coasts of England and Wales.

In parallel with preparatory work on the Regulations, the Department of the Environment, Transport and the Regions have been preparing guidance to explain how the Regulations will work within English waters (Marine Minerals Guidance Note 1 (MMG1)), and to provide a broader policy framework for marine aggregate dredging (MMG2). These two documents will be made available when the Regulations come into force.

One of the key implications of the Regulations will be to make EIA a statutory requirement and bring it to the heart of decision making. MMG2 will include an Annex that contains general advice on the issues that should be considered when undertaking an EIA. A copy of the draft text is provided below. It builds on the advice provided in the MAFF Leaflet 73\(^5\), and recent discussions between DETR, MAFF and CEFAS. DETR has also commissioned CEFAS to develop more detailed guidance on procedures for conducting benthic studies at aggregate dredging sites as part of an EIA process and for monitoring purposes. Details are provided separately.

This Annex is offered to ICES in its draft form as a contribution to discussions on approaches to EIA in respect of marine aggregate dredging.

DETR
April 2000

\(^3\) 85/337/EEC as modified by 97/11/EC
\(^4\) 92/43/EEC
Appendix X


Introduction

B1. The extraction of marine sand and gravel has the potential to impact unacceptably on the coastal environment, commercial fisheries, marine ecosystems, navigational routes, archaeological sites and other users of the sea. It is therefore important that dredging is only undertaken at a location and in a way that does not have unacceptable impacts.

B2. Regulation 4 of the Environmental Assessment and Habitats (Extraction of Minerals by Marine Dredging) Regulations 2000 requires that any person wishing to carry out a dredging operation should first determine from the Secretary of State whether the proposal comprises or forms part of a relevant project. The Secretary of State is required to take account of the criteria set out in Schedule 2 to the Regulations which consider the characteristics of the project, its location and the potential impact (see MMG1). However, as indicated in paragraph 24 of this note, the Government has decided that all applications for new dredging permissions will require an EIA.

B3. The applicant is therefore required to prepare an environmental statement (ES) as part of the application process. This should include such of the information set out in Part I of Schedule 1 to the Regulations as is reasonably required to assess the environmental effects of the relevant project and which the applicant can be reasonably be required to compile, having regard in particular to current knowledge and methods of assessment. However, it must include at least the information set out in Part II of Schedule 1 (see Box 1).

B4. Guidance on the procedural steps to be taken when preparing an ES is explained in MMG1. The following text provides guidance on the issues that should be considered when assessing the environmental effects of the proposed project. It is in four sections, reflecting the requirements of the Regulations:

- Description of the proposed activity and environment
- Assessment of the potential effects of the dredging activity
- Measures to avoid, reduce or remedy significant adverse effects
- Monitoring of environmental effects

Box 1. Schedule 1 to the 2000 regulations

Information referred to in the definition of environmental statement

Part i

1. Description of the project, including in particular -

(a) a description of the physical characteristics of the whole project and the land-use requirements during the construction and operational phases;

(b) a description of the main characteristics of the production processes, for instance nature and quantity of the materials used;
Appendix X

(c) an estimate, by type and quantity, of expected residues and emissions (water, air and soil pollution, noise, vibration, light, heat, radiation, etc.) resulting from the operation of the proposed project.

2. An outline of the main alternatives studied by the applicant and an indication of the main reasons for his choice, taking into account the environmental effects.

3. A description of the aspects of the environment likely to be significantly affected by the proposed project including, in particular, population, fauna, flora, soil, water, air, climatic factors, material assets, including the architectural and archaeological heritage, landscape and the inter-relationship between the above factors.

4. A description of the likely significant effects of the proposed project on the environment, which should cover the direct effects and any indirect, secondary, cumulative, short, medium and long-term, permanent and temporary, positive and negative effects of the project, resulting from:

(a) the existence of the project;

(b) the use of natural resources;

(c) the emission of pollutants, the creation of nuisances and the elimination of waste, and a description by the applicant of the forecasting methods used to assess the effects on the environment.

A description of the measures envisaged to prevent, reduce and where possible offset any significant adverse effects on the environment.

6. A non-technical summary of the information provided under paragraphs 1 to 5 of this Part.

7. An indication of any difficulties (technical deficiencies or lack of know-how) encountered by the applicant in compiling the required information.

Part ii

1. A description of the project.

2. A description of the measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects.

3. The data required to identify and assess the main effects that the project is likely to have on the environment.

4. An outline of the main alternatives studied by the applicant and an indication of the main reasons for his choice, taking into account the environmental effects.

5. A non-technical summary of the information provided under paragraphs 1 to 4 of this Part.
Description of the proposed activity and environment

B5. This should cover the following issues:

- the location of the proposed dredging area should be specified by a list of co-ordinates together with a map showing its location in relation to the surrounding sea area and adjacent coastlines. The size of the area should be specified in square kilometres.

- the total volume of material to be extracted should be stated together with an indication of the maximum depth to which material will be removed.

- a description of the material to be extracted should be given indicating the particle size distribution of the material found within the proposed dredging area. This should be presented as the percentage of gravel, sand and finer material, at representative locations within and adjacent to the application area.

- the type of dredgers to be used should be described (e.g. trailing suction hopper dredger), together with details of the vessels’ load capacity, overflow arrangements and operating methods. It should be made clear whether on-board screening (i.e. rejection of fine or coarse fractions) is to be used.

- proposals should state the proposed annual extraction rate and the predicted lifetime of the deposit.

- estimates should be provided of the likely number of shipping movements on an annual, and where appropriate, seasonal basis, and the number of vessels likely to be operating within the area at any one time. The routes likely to be taken by dredgers to and from the application area should also be specified.

- The applicant should provide details of their proposed operational control procedures to ensure that dredging only takes place in the permitted area and that interference with other users of the sea is minimised both within and outside the proposed extraction area. Applicants should consider appropriate notification and liaison arrangements with other relevant users of the sea (e.g. fishermen) to ensure harmonious working relationships between the different parties.

- Details of the wharves/ports where the extracted marine aggregate is to be landed.

- The need to exploit the resource in question through careful, comparative consideration of local, regional and national need for the material in relation to the identified impacts of the proposal and the relative environmental and social costs of provision from other marine and terrestrial sources.

Description of the physical nature of the seabed

B6. The physical aspects that should be considered include:

- a description of the geology and geomorphology of the application area and its surrounds, including the nearby coast, indicating where possible, its recent evolution.
• bathymetry of the seabed in the proposed area together with a surrounding strip of at least 1km outside.

• assessment of the hydrodynamics of the general area including tidal regime, wave conditions and residual water movements. Notable features on the seabed and indicators of tidal current strength and direction should be identified. Assessment of the mobility of the seabed and sediment transport pathways should be based on direct observations, numerical modelling, or inferred from bedform asymmetry and type.

• the characteristics of the seabed sediments in and around the site should be identified using side-scan sonar and grab sample data. The mineral resource characteristics including its particle size and lithology, origin and composition, thickness, and nature of underlying deposits should be identified.

• a baseline assessment should be undertaken of water quality in the area prior to dredging. This should include an assessment of suspended sediment load, and where appropriate any chemical contamination. An indication of seasonal variability is also necessary.

**Description of the biological status of the proposed area**

**B7.** The benthic survey should be undertaken by properly qualified and experienced personnel. The sampling strategy, including the number of sampling stations, the method used to collect samples and the method of sorting and recording should be agreed beforehand with MAFF and English Nature. Further guidance on appropriate procedures for undertaking benthic surveys will be produced shortly by CEFAS on behalf of DETR.

**B8.** The ES should provide the following:

• a summary of the techniques used, and records of all species identified and their abundance at each sampling station,

• a description of the benthic communities present within and adjacent to the application area. This should include evaluation of the typical assemblages of species, including diversity, abundance, extent, species richness, representativeness, naturalness, rarity and fragility in and around the proposed dredging area,

• an indication of the sensitivities of particular habitats and species, e.g. *Sabellaria* reefs, or *Modiolus* beds.

• an assessment of known predator-prey relationships, and measures of abundance of dominant species likely to be influenced by dredging, including temporal and spatial population dynamics of the benthic assemblages;

• the fisheries resources of the region, including the location of spawning grounds, nursery or feeding areas and migration routes, taking account of seasonal variability;

an assessment of the importance of the general area for protected species such as sea birds and marine mammals.
Other users of the sea

B9. There are many other legitimate users of the sea. It is important that dredging does not cause unacceptable disturbance to them. The ES should identify the extent to which the following activities may be affected by dredging.

(a) Commercial fishing activity. The ES should include:

- an assessment of the nature and level of commercial fishing activities in the vicinity of the application area. This should involve consultation with the fishermen’s organisations, and analysis of published statistics on fish landings from the dredged area. However, since published statistics are normally on too coarse a scale, fishermen’s logbook data and special fishery intensity studies are preferred. Statistics should cover a period before dredging starts to provide a baseline. The natural fluctuations in fish populations from year to year mean that ideally, a number of years of pre-dredging data is required.

- information about the recent and current numbers of vessels and fishing patterns in the area, together with species, quantities and values of catches from the area, indicating the extent of seasonal activity. Consideration should be given to the number of vessels operating out of the various ports, and fishing methods used. This will have a bearing on the time that fishing gear is left at the seabed, and therefore the amount of warning required in advance of dredging operations commencing.

- for each commercial species, details of the weight of catch and catch value for each port of landing. Since official statistics are generally thought to underestimate the true landings there is a need to adjust the figures accordingly to predict the actual catch.

- using the catch information, provide an estimate of the proportion of the landing at a particular port, relating this to the amount of fishing effort over the application area. This gives some indication of the relative contribution that the application area makes to the total catch and therefore gives some indication of the commercial value for fishing of the application area.

(b) other dredging activities in the area;

- waste disposal operations (by dumping or pipeline) in the region;

(d) offshore oil and gas activities which might impact or limit dredging;

- marine archaeology e.g. wrecks and war graves;

- shipping and navigational hazards;

- location of military exercise areas;

- location and magnitude of recreational activities such as yachting, angling and SCUBA diving;

- location of pipelines, cables and other such features;
Appendix X

- location of designated conservation areas (SSSIs, SACs and SPAs) and heritage areas (Heritage Coast, AONB).

**Assessment of the potential effects of the dredging activity**

B10. When evaluating the potential effects of the proposed dredging program the ES should identify and quantify the consequences of the proposal. Ideally, this should be summarised as an impact hypothesis, drawing on the results of earlier studies. The assessment of some of the potential impacts will require predictive techniques, and it may be necessary to use appropriate mathematical models. Where such models are used there should be sufficient explanation to enable an informed assessment of their suitability for the particular modelling exercise to be undertaken.

B11. The ES will also need to demonstrate that a permission is unlikely to result in unacceptable cumulative physical and/or biological impacts i.e. the combined effects of dredging and other activities in nearby areas as well as within the proposed dredging area.

**Physical effects of dredging**

B12. To assess the physical impact of aggregate extraction on the hydrographic and seabed environments, information should be provided on:

- likely production of a sediment plume (from the draghead at the seabed, from hopper overflow, or on-board screening) and its subsequent transport within the water column or along the seabed. This should be considered together with the background suspended load.
- implications for coastal erosion (through a Coastal Impact Study), in particular;
  - whether the dredging is far enough offshore for there to be no beach draw-down into the deepened area;
  - whether the dredging will interrupt the natural supply of materials to adjacent beaches through tides and currents;
  - the likely effect on bars and banks which provide protection to the coast by absorbing wave energy, and the potential impact on local tidal patterns and currents;
  - likely changes to the height of waves passing over dredged areas and the potential effect on the refraction of waves leading to significant changes in the wave pattern;
- the likely effects on the seabed of removing material. In particular the nature of the sediment to be left once dredging ceases, and the likely topography (e.g. ridges and furrows);
- implications for local water circulation resulting from the removal or creation of topographical features on the seabed;
- assessment of the impacts in relation to other active or proposed dredging operations in the area.
B12. Further guidance on assessing the effects of dredging on the coastline is contained in ‘Regional seabed sediment studies and assessment of marine aggregate dredging’ produced by CIRIA.

**Biological effects of dredging**

B13. The principle biological impacts of dredging are direct disturbance and removal of benthic species, and alteration of the nature of the seabed upon which colonisation depends. This can affect the suitability of the seabed as a fish or shellfish food resource or habitat. Dredging should aim to leave the seabed in a similar physical condition to that present before dredging started to enhance the possibility of, and rate at which, the seabed recovers physically and biologically to its pre-dredging condition.

B14. The EIA should consider:

- variability of benthic species and communities over time and spatially, together with an indication of the likely rate of recovery following the cessation of dredging;

- the potential impact on the fish and shellfish resources, both within and outside the application area. Particular attention should be given to spawning and nursery areas and overwintering grounds for ovigerous crustaceans (for example, egg bearing lobsters and crabs) and known migration routes.

- Potential impacts on seabirds, marine mammals, and sharks.

**Effects on other users of the sea**

(a) Potential effects on commercial fisheries

B15. Dredging has two potential effects on commercial fisheries. The first is to modify the marine environment in such a way that it affects fish stocks, for example, by interfering with fish spawning and nursery areas, or migration routes. The second is the direct effect on the activities of fishermen.

B16. Consideration should be given to the noise and the sediment plumes which dredgers may cause, which could result in the temporary movement of fish out of the area, and could therefore put some fisheries out of the reach of smaller vessels.

B17. Dredging may also affect fish stocks indirectly, by disturbing benthic communities which provide the food source for commercial fish. Depending on the size of the area affected, highly mobile fish species may be able to move to other feeding grounds. But this can affect local fishermen. The ability of fishermen to avoid dredging areas will vary depending on the fishery they pursue and the size and complexity of their boats.

B18. MAFF should be consulted on the availability of information on such matters as the location of spawning areas, important known feeding/nursery grounds, migration routes and over-wintering grounds for egg-bearing crustaceans.

(b) Other activities
Careful consideration will need to be given to applications which may interfere with other users of the sea, shipping lanes, areas adjacent to buried pipelines and cable routes, wrecks and MOD sites. The effect on sports fishermen, leisure craft and divers should also be carefully considered.

**Potential effects on marine archaeological sites**

B19. The Joint Nautical Archaeology Policy Committee has produced a Code of Practice for Seabed Developers. This provides recommended procedures for consultation and co-operation between seabed developers and archaeologists. This is consistent with the Government’s policy on archaeology as stated in PPG16 and should continue to be followed by the dredging industry. The Secretary of State will have regard to the Code in considering applications for dredging permissions.

**Measures to avoid, reduce or remedy significant adverse effects**

B20. The ES should include consideration of the practical steps that might be taken to mitigate the effects of the proposed mineral extraction. These should be site specific and closely linked to particular potential environmental effects identified during the EIA process. Mitigation measures may include:

- modification of the dredging depth to limit changes to hydrodynamics and sediment transport patterns to acceptable levels;
- agreed dredger navigation routes to minimise interference with shipping, fishing and other users of the sea;
- a zoning of the permitted area to protect sensitive fisheries, optimise access to traditional fisheries, and to reduce the impact on sensitive benthic assemblages;
- exclusion zones to protect rare or stable communities identified as occurring in small areas within a much larger application area. Such exclusion zones also provide a refuge for species that may assist in the eventual recolonisation of the worked-out area. Where such an approach is considered appropriate, it is important that the exclusion zones are large enough to protect the area of critical importance.
- the choice of dredging technique and the timing and phasing of working may also assist in preventing disturbance. For example it may be appropriate to allow dredging only at particular stages of the tide to ensure that disturbed sediments are taken away from exclusion zones by the tide.
- seasonal restrictions, where appropriate, to minimise impacts on migratory fish stocks or on vulnerable life history stages of fish or the benthos;
- safety buffer zones around important wrecks, war graves, or other marine archaeological sites, pipelines and cables;
B21. It may often be necessary to seek expert advice to devise measures to protect species such as seabirds, and marine mammals, where these are at risk. Such advice may be available from English Nature.

B22. When considering mitigating measures, a balance has to be struck between the ecological or other importance of the area and the level of protection afforded to it. If an area is identified to contain or, in some other way, to support (e.g. as feeding grounds) important species, this may be sufficient cause to prevent dredging (or other forms of seabed disturbance) altogether.

**Monitoring of environmental effects**

B23. Conditions attached to permissions are aimed at minimising environmental effects by controlling the operation of dredging activity. However, in many cases it is not possible to predict all the environmental effects at the outset. A program of monitoring can be used to assess the validity of the predictions made in the EIA as well as establishing whether the dredging conditions are adequately preventing unacceptable effects on the marine and coastal environment, fisheries and other users of the sea. The ES should include a consideration of an appropriate monitoring program.

B24. Monitoring should take account of natural variability within the marine environment. This can best be achieved by comparing the physical or biological status of the dredging area with reference sites located away from the influence of dredging effects.

B25. The spatial extent of sampling should take account of the area permitted for extraction and areas outside which may also be affected. In most cases there should also be monitoring within an area where ‘no effect’ is expected. This will give a better indication of the extent of any effects.

B26. The frequency of monitoring will depend on the nature of the area of interest, including its sensitivity and the anticipated period of consequential environmental changes.

B27. Reports on monitoring activities should be prepared. These should provide details of the measurements made, results obtained their interpretation and how the data relate to the monitoring objectives.

B28. Monitoring operations are expensive, as they require considerable resources both at sea and in subsequent sample and data processing. It is important, therefore, to ensure that a monitoring program is properly designed so that it meets its objectives. The results should be reviewed at regular intervals against the stated objectives and the monitoring exercise should then be continued, reviewed or even terminated.
Executive Summary of
U.S. Dept of Energy National methane hydrate multi-year
R&D program plan

The full text of this document is available at the following URL:

NATIONAL METHANE HYDRATE MULTI-YEAR R&D PROGRAM PLAN

U.S. Department of Energy
Office of Fossil Energy
June 1999.

Executive Summary
Methane hydrates represent a potentially enormous natural gas resource. Estimates range as high as 700,000 trillion cubic feet (Tcf) worldwide, many times the estimated total of world-wide conventional resources of natural gas and oil. For the United States, resources are estimated in the range of 100,000 to 300,000 Tcf. If it is determined that the safe production of methane from hydrates is technically feasible and economically viable, the Nation’s economic growth would be revolutionised, long-term energy security would be ensured, and environmental quality would be improved.

In its 1997 Report on Energy Research and Development for the Challenges of the Twenty-First Century, the President’s Committee of Advisors on Science and Technology (PCAST) included a principal recommendation that the Department of Energy (DOE) Office of Fossil Energy (FE) develop a science-based program with industry and other Government agencies to “understand the potential of methane hydrates world-wide.” The PCAST view was that methane hydrates were not being addressed adequately in FE, or in other DOE R&D programs and agencies, and that more emphasis through applicable R&D was needed. The PCAST suggested first-year funding of $5 million, rising to $12 million in the fifth year. The current consensus of DOE and its industry and academic advisors, based upon the additional knowledge acquired in the last year, is that a methane hydrate R&D program of $150 to $200 million over a ten-year period will be needed to accomplish mission goals.

In addition to the PCAST recommendation for an initiative on methane hydrates, draft legislation –U.S. Senate Bill S. 330 and the U.S. House of Representatives companion Bill H.R. 1753, The Methane Hydrate Research and Development Act of 1999 – promotes the research, identification, and development of methane hydrate resources. This is an authorisation bill and thus does not appropriate funds, but these House and Senate actions
Appendix XI

clearly indicate Congressional support for a National R&D program. The Act is expected to be enacted into law in 1999.

DOE/FE, in collaboration with other agencies, academia, and industry, is poised to implement a program which builds upon the existing knowledge base to investigate and obtain the information necessary to bring methane hydrates into the natural gas resource base. The National Methane Hydrate Multi-Year R&D Program Plan builds on the 1998 DOE report, A Strategy for Methane Hydrate Research and Development, is responsive to the PCAST recommendations, and wholly consistent with the FE mission to ensure National energy security through providing an abundant domestic source of natural gas. The Program promotes the introduction of critically needed information, which would not otherwise be available in the marketplace, enabling the private sector to further develop and safely apply the new technologies commercially.

The National Methane Hydrate Multi-Year R&D Program Plan illustrates how technology is expected to proceed from the current state-of-the-art to the technological level needed to achieve Program goals. The Federal role provides for the coordination, integration, and synthesis of research efforts needed to: (1) establish an estimate of gas resources from methane hydrate deposits; (2) develop the technology necessary for the commercial production of methane from hydrates; (3) understand and quantify the dual roles of methane hydrates in the global carbon cycle and their relationship to global climate change; and (4) respond to industry concerns regarding the safety and sea floor stability issues and pipeline plugging concerns attributed to methane hydrates which are currently associated with the exploration, production, and transportation of conventional hydrocarbons. The R&D Program is framed as four technology areas which will share data, theoretical concepts, and results. Furthermore, the activities within each technology area will not occur separately nor sequentially; data collection, laboratory experiments, modelling, and field validation will proceed in parallel to promote synergy. Aggressive technology transfer activities, including an on-line database, will stimulate research and serve to monitor and sustain its quality while avoiding duplication of efforts.

The four technology areas are:

(1) **Resource Characterisation**
This key activity includes the work required to prepare, analyse, evaluate, and develop the databases, mapping systems, and models necessary to understand and characterize methane hydrate deposits in the geologic environment, and accurately estimate the methane resource available in hydrate deposits. Much of the information accrued in this activity will also provide the basis for the Global Carbon Cycle and Safety and Sea Floor Stability research areas.

(2) **Production**
The goal of this activity is to develop the knowledge and technology needed for commercial production of methane from oceanic and/or permafrost hydrate systems by 2015. Specifically, the activity will develop the foundation of basic scientific information necessary for the safe, environmentally responsible, and commercially attractive production of methane from hydrates. Reservoir and process engineering modeling, and economic analyses will be conducted; and conventional recovery technologies, along with novel, innovative alternative recovery technologies will be tested and evaluated.

(3) **Global Carbon Cycle**
Natural releases of methane from hydrates may add to the atmospheric carbon budget either directly as methane, or indirectly as carbon dioxide, through chemical or biological oxidation. Conversely, utilization of methane from hydrates would provide a vast resource of low-carbon fuel that could displace more carbon-intensive fossil fuels as part of a strategy for reducing atmospheric levels of anthropogenic greenhouse gases. This activity seeks to understand and quantify the dual roles of hydrates in the global carbon cycle and their relationship to global climate change.

National Methane Hydrate Multi-Year R&D Program Plan

(4) **Safety and Sea Floor Stability**

This activity will be co-developed and integrated with the Resource Characterisation effort. Early emphasis will be focused on near-term solutions to the petroleum industry’s concerns of both safety and sea floor stability, due to methane hydrate occurrence associated with the exploration, production, and transportation of conventional hydrocarbons. A report, Advanced Mitigation Recommendations, will document the findings in this research effort, and offer practical solutions, optimally providing low-cost problem recognition/avoidance solutions. Possible and predictable future trends in global warming effects that could exacerbate safety and/or sea floor stability due to hydrate dissociation will be monitored and activities adjusted accordingly.

The mission of the National Methane Hydrate Multi-Year R&D Program is to carry out the research, development, and demonstration necessary to identify and enhance options that could revolutionise 21st century energy markets through the commercial production of methane from hydrates in a safe and environmentally responsible manner.
Appendix XII

Transcript of Personal Communication from Michael D Max.

Dr. Michael D. Max
2457 39th Place NW Washington DC 20007
Tel/Fx:202-333-7420 e-mail: xeres@erols.com

February 29,2000
Gerry Sutton
Coastal Resources Centre
National University of Ireland,
Cork Old Presentation Buildings
Western Road Cork,
Ireland

Dear Gerry,

I enclose a few publications for you to look through and a list of my recent publications,
most of which have to do with hydrates in one form or the other.
I have left the Naval Research Laboratory and set up my own company and thus I didn't get
your fax until today. Although i have a consulting contract with NRL, I only go into my old
office irregularly. Note the above contact numbers.
So far as I know, no one has looked at the seismic around Ireland for evidence of hydrate  (it
often is not terribly obvious to a conventional exploration geologist/geophysicist), and the
settings under which the seismic was acquired and processed need to be taken into
consideration. The couple of paragraphs of information requirements are pretty standard for
everywhere, but involve a lot of work, including looking at available seismics of all types.
So far as the possibility of significant hydrate concentrations around Ireland (I include the
Rockall), it is safe to say that no one knows. The most appropriate strategy for assessing an
initial hydrate evaluation is to hire some consultants who have the experience of evaluating
hydrate elsewhere to do an initial assessment of the Irish Sea area.
I guess the long and short of it is that if you want a proper evaluation done, I or my
colleagues are prepared to consider doing it, but it would have to be done on a consulting
basis. If you want to pursue hydrate evaluation with me, contact Viv Byrne at CSA in
Dublin. I have asked him to be my representative for this type of specialist work in the Irish
Sea area.

Sincerely Michael D. Max
Appendix XII


McDonnell, S.L. & Max, M.D. 1999. Oblique collision of an oceanic crust subduction zone with continental crust: The Taiwan flip and pop-up structure. (Submitted)


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Appendix XII


Appendix XII


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