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MARINE GEOLOGY IN ATLANTIC CANADA - A GOVERNMENT PERSPECTIVE[1]

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The two priorities for government marine geoscience over the next decades are: (1) seabed mapping for ocean management, including safe and sustainable use of natural resources; and (2) societal responses in the coastal zone to natural hazards, global climate change and anthropogenic pressures including environmental degradation. Meeting these priorities will require scientific study of the history of past glaciations; erosion, transport and flocculation processes of sea-floor sediments, particularly of muds; and sediment transport and deposition and their interaction with environmental quality in estuarine systems, including the role of ice and storms. Numerical models are required to predict the consequences of natural rise in sea level and human interference in coastal systems and for predictive decision making in ocean management. Three recent revolutionary developments in technology will influence how science is done: these are the development of Global Positioning Systems (GPS), of multibeam sonar, and of digital data collection, storage and dissemination. However, other capital acquisitions and technological developments are necessary. These include new ships, expanded multibeam capability, and underwater autonomous vehicles. New photographic/video systems will provide resolution higher than that of multibeam bathymetry. In the coastal zone, remote sensing tools such as Light Detection And Ranging (LIDAR) and kinematic GPS will accelerate monitoring of coastal change. Cabled seabed observatories will provide time series and real-time information on extreme events. Research boreholes are essential to understand geological framework.

Les deux priorités du programme gouvernemental de géologie marine au cours des 20 prochaines années sont les suivantes : (1) cartographie des fonds marins pour la gestion des océans, et notamment l'utilisation sécuritaire et durable des ressources naturelles; et (2) les réponses sociétales, dans la zone côtière, aux risques naturels, aux changements climatiques planétaires et aux pressions anthropogéniques, notamment la dégradation de l'environnement. Pour réaliser ces priorités, il faudra procéder à des études scientifiques sur l'histoire des glaciations passées; l'érosion, le transport et la floculation des sédiments des fonds marins, en particulier des boues; le transport et le dépôt des sédiments ainsi que leurs relations avec la qualité environnementale dans les systèmes estuariens, notamment le rôle de la glace et des tempêtes. Des modèles numériques sont nécessaires pour prévoir les conséquences de l'élévation naturelle des niveaux marins et des interférences humaines dans les systèmes côtiers, de même que pour prendre des décisions prévisionnelles en gestion marine. Trois progrès révolutionnaires récents de la technologie vont avoir une influence sur les modes d'exécution des activités scientifiques : le développement du GPS, le développement du sonar multifaisceau ainsi que la collecte, le stockage et la diffusion des données numériques. Cependant, il faudra d'autres équipements et innovations technologiques,

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comme de nouveaux navires, d'autres dispositifs de sondage multifaisceau ainsi que des véhicules sous-marins autonomes. De nouveaux systèmes photographiques et vidéo offriront une résolution supérieure à celle de la bathymétrie multifaisceau. Dans la zone côtière, certains outils de télédétection (comme le LIDAR) et le GPS en mode cinématique vont accélérer l'observation des variations côtières. Des observatoires de fonds marins câblés fourniront des séries chronologiques et des données en temps réel sur les événements extrêmes. Des sondages de prospection seront essentiels à la compréhension du cadre géologique.

INTRODUCTION

Published scientific knowledge of the geological nature of the seafloor off Atlantic Canada first appeared in the second half of the 19th century, at first as a result of observations made by fishermen and from the laying of telegraph cables. Professor J.W. Bailey's studies of seafloor samples from east of Newfoundland in 1856 revealed volcanic ash, which he suggested might have been dropped from icebergs (Maury 1859). HMS *Challenger* visited Halifax as part of its investigation of the world ocean, dredging a granite boulder from south of Nova Scotia (Gossip 1873). US government investigations of the fishing banks (Verrill 1878) led to the recognition of the Grand Banks as an analogue of the Atlantic coastal plain of the eastern USA. Over the same time period, scientific studies of the coastal zone were the result either of the need to survey charts for safe navigation, or were an extension of studies of rocks on land. For example, Lyell (1849) studied the mudflats of the Bay of Fundy, applying his observations to the interpretation of ancient rocks. In his second edition of *Acadian Geology*, Dawson (1868) ascribed many of the coastal landscape features of Nova Scotia to the combination of sea-level changes and ice. Beach mining was an important source of aggregate at this time - "large quantities of ballast stone were sold annually" from McNabs Island in Halifax Harbour in 1849 and the same beaches supplied "a splendid brickworks" in 1855 (Manson 1999). The Saxby Gale of 1869, scientifically predicted by Stephen Saxby and Frederick Allison (http://www.magma.ca/~jdreid/saxby_gale.htm), resulted in widespread coastal damage in the Bay of Fundy and was probably the most devastating natural disaster in recorded history in New Brunswick (Ruffman 1999).

A century and a half later, we can still recognise 19th century themes in the issues and approaches to marine geoscience in Atlantic Canada. Economic pressures for marine geology research come from those exploiting the seafloor - the fishery and in the 21st century, the oil and gas industry. Seafloor communications are no longer by telegraph, but through fibre-optic cables, and the seafloor is also used for electricity transmission cables and gas pipelines. Understanding of the geological framework and geological processes is necessary for safe and sustainable management of seabed resources. In the coastal zone, although the ravages of beach mining have largely been halted, the sheer numbers of people wanting to live near and use the coast continues to increase. Causeways, bridges, docks, marinas and shoreline protection structures impact the stability of the coastline. Coastal communities, and particularly the larger urban centres, have been subjected to nearly three centuries of waste disposal and marine environmental quality has suffered accordingly. As in Saxby's time, there is a need to predict the effects not only of storms, but also of the continuing rise of sea level, both exacerbated by global warming. Fundamental science provides the intellectual underpinning for effective human use of the sea floor and coastal zone, and as in the mid 18th century, scientific progress results from a mix of indigenous studies and international work on the world ocean.

This review considers the role of marine geoscience in government science in the coming decade in Atlantic Canada, from the perspective of the Geological Survey of Canada. Clearly, this government science will not be carried out in isolation, and important contributions will come from universities and the private sector, but both of these sectors respond to pressures that are different from those affecting government science. Regrettably, marine geoscience is highly dispersed in the Canadian university system, and does not achieve a critical mass in any single university. In Atlantic Canada universities have found it difficult to access Canadian ship-time and despite some successful collaborative projects with the government agencies, much of the Atlantic Canadian university effort in marine geoscience is carried on outside Atlantic Canada waters. Globally, research in industry has become focussed in fewer larger multinational companies and, consequently, industry in Atlantic Canada has limited Research and Development (R&D) capacity in marine geoscience and has traditionally looked to government agencies for that expertise. Recently, Petroleum Research Atlantic Canada (PRAC) (http://www.pr-ac.ca/), funded by oil companies developing reserves in Atlantic Canada, has identified a series of research priorities of interest to the petroleum industry and is providing support to universities and industry for such work. In contrast, the Atlantic Innovation Fund, established by the federal government in 2001 to encourage research to stimulate economic growth in the region, has only invested in marine geoscience indirectly through, for example, the petroleum-related Pan Atlantic Petroleum Systems Consortium.

SEAFLOOR MAPPING AND INTEGRATED OCEAN MANAGEMENT

In the next decade, the area of greatest change and advancement will likely be in seafloor mapping and its application to integrated ocean management. The advent of precise positioning through Global Positioning Systems (GPS) in parallel with the development of multibeam bathymetric tools has enabled rapid, high-resolution mapping of bathymetry and backscatter (a proxy for sediment type). In hydrocarbon basins, this is complemented by industry acquisition of 3-D seismic data that can be processed to provide high resolution bathymetry. These spatial data provide a context within which conventional point (sample, photography) and line (seismic, sidescan profile) data can be interpreted.

These new tools have revolutionized seafloor mapping. For the first time, they allow a view of the seafloor comparable with satellite imagery on land. They support many of the traditional applications of seafloor mapping: cable and pipeline routes, foundation conditions for seabed structures, the scale of bedforms that indicate sediment transport, intensity of iceberg scouring, offshore extension of bedrock structures, and the nature of the substrate for military applications (mines and sonar). They provide new insights into scientific issues such as the positions of former ice margins, ice-flow directions, drainage systems and former coastline positions and thus will make a major contribution to ice sheet and sea-level reconstruction and modeling.

Canada is a leading player in the emerging global awareness of such new tools and the development and application of the new map products to management of sustainable resources. In particular, habitat mapping is developing as a major new application of geoscience throughout the world as nations recognize the need to move from management of a wild fishery to ecosystem based management. Substrate is a primary control on benthic community structure (Kostylev et al. 2001). Precise maps of substrate allows bottom fishing effort to be managed in a manner more akin to agriculture than to hunting.

Canada, through the Department of Fisheries and Oceans (DFO), is a world leader in recognizing the need for an integrated approach to ocean management. The Canada Oceans Act of 1997 provides the legislative framework for development and implementation of a national strategy for ocean management, including the establishment of Marine Protected Areas (MPAs) and Large Ocean Management Areas (LOMA). The recently announced Oceans Strategy (http://www.cos-soc.gc.ca/) provides the vehicle to deliver on this legislation: seafloor mapping is at the core of the Oceans Strategy, acknowledging the power of the new tools and the need for a national program to systematically map the offshore lands. The need for ocean management arises from the multiple conflicting uses of the ocean floor - by various fisheries and aquaculture, by ecotourism, by hydrocarbon production platforms and pipelines, by telecommunication and electricity cables, and potentially for aggregate mining and in some inshore areas, for mining of placer minerals (Pickrill & Todd 2003). In addition, MPAs need to be set aside to preserve marine habitat and environmental diversity. Emergence of the concept of integrated ocean management, embodied within legislation and embracing the principles of a precautionary approach and sustainablity, provides a framework for decision making and establishing research priorities. Natural Resources Canada (NRCan), in partnership with the DFO, recognised the need to systematically map Canada's offshore lands to deliver the knowledge for ocean management and have completed extensive cross country consultations and feasibility studies to scope a national seafloor mapping program (SeaMap).

Canada has recently ratified the United Nations Convention on the Law of the Sea (UNCLOS) (http://www.dfait-maeci.gc.ca/department/focus/UN-

CLOS-en.asp). The Atlantic margin of Canada is exceptionally wide and is potentially open to an extended margin claim. Preliminary estimates (Macnab 1994) suggest Canada could gain as much as 1.76 x 106 km^2 new territory in offshore lands, i.e. equivalent to the area of the three prairie provinces. The bathymetric and sub-surface geological basis of such a claim unquestionably includes seaward extension of the continental shelf and slope beyond the current 200 mile territorial limit offshore both Nova Scotia and Newfoundland; the federal government has recently funded hydrographic and seismic surveys to support this case. Hydrocarbon exploration is already underway in lease blocks that extend beyond the current 200 nautical mile limit off Newfoundland. Territorial claims will be one of the emerging issues (along with hydrocarbons) that will continue to drive geoscience R&D beyond the edge of the continental shelf.

The petroleum industry is at present one of the principal users of government geoscience R&D. The cyclicity of the industry and the global nature of most of the large companies means that the wealth of corporate knowledge built up during the last phase of heightened exploration in the late 1970's and early 80's is no longer available to most of the companies. Consequently, companies active in the east coast offshore today lack a detailed knowledge of the regional geology of the seabed or of some of the unique conditions that occur. Sable Island Bank, the Grand Banks, and the Scotian Slope all have unique geohazards and foundation conditions that are quite different from those in the Gulf of Mexico or the North Sea. The offshore regulators Canada Newfoundland Offshore Petroleum Board (CNOPB), and Canada Nova Scotia Offshore Petroleum Board (CNSOPB) lack R&D capacity and look to government science programs to provide an independent evaluation of geohazards and environmental risk in offshore development. At present, issues on the continental shelf are concerned mainly with the stability of production facilities and the routing and stability of pipelines. Monitoring of the environment and sediment process studies are thus important in these areas. The new frontiers are in deep water, on the continental slope off Nova Scotia, parts of the Grand Banks, Flemish Pass and Orphan Basin, with the possibility that exploration will once again move to offshore Labrador and the Gulf of St Lawrence. Geohazards are poorly understood and spatially variable so that definition of the regional geological framework is the key activity in these areas.

Offshore aggregate has potential to become a valuable industrial mineral in Canada over the next 50 years. In areas such as western Europe, as much as 20% of aggregate resources are derived from the North Sea. Nova Scotia, in particular, has proven shallow water reserves and is well placed to supply markets in the northeastern USA. Feasibility studies are being considered for commercial development. The government science role will include both resource assessment and development of an acceptable code of environmental practice. Before a new industry can develop, a legislative and regulatory framework needs to be established for offshore mining. At present, the Department of Natural Resources Canada (NRCan) is obligated to provide mineral resource assessments of all proposed MPAs to ensure future offshore resource development is not compromised.

THE COASTAL ZONE: BEACHES, ESTUARIES AND HARBOURS

The challenges in the coastal zone of Atlantic Canada are driven by two main factors. One is the natural rise in sea level (of a few mm per year in much of southern Atlantic Canada, but falling in parts of northern Newfoundland and elsewhere in northern Canada), in all probability accelerated by the impact of global climate change. The second is the maintenance of environmental quality in estuarine and other coastal systems under pressure from population increase in the coastal zone and increasing use of the marine environment by industry, aquaculture, and recreation.

Canada has the longest coastline of any nation in the world, yet generally a very low population density near the coast. The national strategy is thus to accommodate to natural and enhanced coastal retreat as sea level rises. Locations where key infrastructure is at risk will provide the exception to this strategy. Consequently, research needs to focus on vulnerable shores with the greater population densities and on predicting shoreline change on say 20, 50 and 150-year time frames. Until recently, high resolution studies of coastal change were laboriously time consuming. The advent of increasingly higher resolution remote sensing techniques, such as satellite imagery and LIDAR, are changing our ability to effectively study large areas of the coast. Research will necessitate continuing maintenance of coastal monitoring networks and a thorough understanding of nearshore processes and sediment budgets. Changing climate will focus research on impacts and adaption to both continuous change and extreme events.

Because of the societal consequences of coastal retreat, geoscience will increasingly need to be taken to the affected communities in an integrated manner, partnering with social scientists, engineers and planners (as done recently for the City of Charlottetown; McCulloch 2002). Communities need to be involved and empowered, which will require the preparation of information and tools that can be readily used by groups to address their own issues. Knowledge dissemination to communities is a far greater challenge than the geoscience information needs for offshore regions, where there are a small number of users who either have substantial technical competence or can be brought up to speed rapidly on a one-on-one basis. Initiatives such as Coastweb (http://agcwww.bio.ns.ca/COASTWEB/) and the establishment of the Climate Change Impacts and Adaptation Research Network (C CIARN) at the Bedford Institute of Oceanography (BIO) are attempts to provide effective communication. They form part of a general trend in government to make all “knowledge” available on line, with user-friendly digital products.

Many coastal communities are founded in marine based economies. Following collapse of the ground fishery, the challenge has been to establish a broader sustainable economic base in our estuaries and harbours and coastal waters. Exploiting new opportunities, such as aquaculture and ecotourism, and balancing these with historical and culturally engrained practices will present a new set of challenges requiring basic research into the understanding of estuarine circulation and sedimentation and the impacts of anthropogenic activity such as waste disposal, dredging and fish farming on coastal systems. Research will be cross disciplinary, have a process focus, and necessitate close partnerships between geoscientists, biologists and oceanographers. Sustainable economic development in rural and coastal communities must address issues of integrated coastal zone management and marine environmental quality.

THE GEOLOGICAL FRAMEWORK

Understanding the geological framework of Atlantic Canada is essential for effective management of the seabed and the coastal zone. Several key issues are identified. The rheology and state of stress in the Earth's crust and its resulting deformation are a consequence of regional plate tectonics and past and present loading, particularly the effects of ice loading 20 to 10 thousand years ago (Peltier 2002) and the effects of sediment loading (Courtney & Piper 1992). The effects of past ice-loading are largely responsible for the present rates of relative sea level rise of several mm a year in much of Atlantic Canada (Shaw et al. 2002) and improved understanding of past ice-loading will enhance future prediction of future sea level rise (www.dal.ca/~cnef/NewFiles/Acid-wkshp-proc'02.doc).

The history of past glaciations is important not only for understanding crustal deformation. The morphology of the continental shelf is largely a consequence of glacial erosion. The upper tens to hundreds of metres of sediment beneath the seafloor on the outer continental shelf and deep continental margin were deposited either directly from glacial ice that extended to the shelf edge only 20 thousand years ago, or from glacial meltwater laden with sediment eroded from Atlantic Canada. Glaciation provides a paradigm for understanding and thus predicting seabed conditions in Atlantic Canada (Syvitski 1993). Improvements in our understanding of glacier dynamics, new data from critical offshore areas, and the chronological revolution provided by Accelerated Mass Spectrometry (AMS) radiocarbon dating mean that a new synthesis of the glacial history of Atlantic Canada including the marine realm is both necessary and timely.

The transport of sand on banks of the continental shelf is reasonably well understood as a result of studies in the last two decades and a predictive modelling capability has been developed (Amos & Judge 1991) including the evolution of "community models" (http://woodshole.er.usgs.gov/project-pages/sediment-transport/). However application has been limited to a few demonstration projects related to engineering infrastructure, such as the Sable offshore gas field. Broader application is required to understand regional sediment dynamics and bank stability on the shallow Scotian Shelf and in the deeper water of the upper continental slope, to support planning for offshore development and habitat management. Fine grained marine sediments are the ultimate depocentres for many terrestrial pollutants. The understanding of transport, sedimentation and erosion of fine grained sediments, particularly in the coastal zone, is minimal.

Over the past two decades, the description of beaches and large-scale processes of cliff retreat and barrier-beach failure have been synthesised in robust conceptual models of the response of beach systems to rising sea level, storms, and beach mining. Many of the processes, however, are stochastic, and with the great developments in numerical modelling in the past decade, there is now a need for much more effective numerical models to evaluate the consequences both of natural rise in sea level and human interference (such as the re-opening of old causeways) on beaches and the estuarine systems behind them.

Estuaries and harbours were the earliest focus of marine geology at BIO, with work on Chedabucto Bay, Baie des Chaleurs, the Bay of Fundy, and Halifax Harbour, but have been largely neglected in Atlantic Canada since the 1970's. In more densely populated areas of the world, embayments such as Chesapeake Bay, Long Island Sound, and the Strait of Georgia continue to be intensively investigated. Such studies are directed at understanding sediment transport and deposition and their interaction with environmental quality, as a result of population pressures including sewage discharge, dredging and ocean dumping. Atlantic Canada shares many of these issues but also has unique scientific problems in coastal embayments. Tidal range and sediment transport in the Bay of Fundy are extreme, resulting in rapid siltation seaward of structures such as coastal causeways. The presence of winter sea-ice over much of Atlantic Canada is a complication absent in most densely inhabited estuarine regions. The “shallow fiord” coastline of much of the Atlantic coast of Atlantic Canada (Stanley 1968) results in sediment dispersion and distribution quite different from that of either low-lying coastal estuaries or of deep fiords (Piper et al. 1983). Many of the fundamental processes of sediment transport and deposition remain poorly understood.

THE NEW SCIENTIFIC TOOLS

Much of the equipment utilised by marine geologists in offshore surveys has changed little over the last 20 years. The basic mapping tools of high resolution seismics and sidescan sonar have witnessed incremental improvements (e.g. chirp seismics), but the coarse glacially derived sediments of the Atlantic margin still present a challenge to high resolution seismic reflection profiling. Bottom camera systems have improved, digital videography has replaced film, and bottom sampling has seen the development of video grabs and improved corers, but again improvements have been incremental rather than revolutionary. The three most significant advances that have and will continue to change our research procedures and advance our scientific understanding are:

1) The development of GPS, providing routine accurate positioning and repeatability
2) The development of multibeam sonar, providing the first accurate high-resolution imagery of the seabed and of automated processing routines for multibeam and backscatter.
3) The transition to digital data collection, and the associated computer capability to manipulate large data sets, process them and distribute products through the World Wide Web.

Marine geoscience survey practice has been transformed from a single ship operation to a two step survey, i.e., a regional multibeam mapping program followed up by targeted "ground truth" surveys utilising traditional tools but much less ship time. Canada, through a partnership with the Canadian Hydrographic Service (CHS), the Geological Survey of Canada (GSC) and the University of New Brunswick, has been at the forefront in adopting multibeam technology and applying it to geoscience. Canada has state-of-the-art equipment and major regional surveys are being conducted, but additional capacity is required to enable these new survey practices to become routine. Nevertheless, multibeam sounding has probably provided a greater leap forward in our understanding of marine geology in Atlantic Canada than in most other parts of the world. The wide, shallow continental shelf, glacial and transgressive history, and energetic seabed have left bedrock, moraines and till exposed at the surface to be modified by hydrodynamic processes. The seascapes emerging from multibeam surveys are spectacular, always providing unexpected insights into our understanding (Fig 1).

For the most part, government marine geoscience research is conducted from the government research fleet, operated and managed by DFO. This research fleet is old – the CCGS *Hudson*, commissioned in 1962, is the only blue water research vessel available for the Atlantic margin. The fleet requires modernisation with cost effective ships for shelf and open ocean deep-water work. Multibeam capability was originally provided for hydrographic needs, but as utilisation has extended to other mandates this capacity has proven to be inadequate, and new systems are required from coastal to deep water environments. It is likely that autonomous underwater vehicles (AUVs) will become the platform of choice for multibeam in the next decade.

The oil industry has driven the improvement in seismic reflection techniques to better define hydrocarbon reservoirs. Globally, 3D seismic reflection has provided the revolution in subsurface imaging that the multibeam instrumentation has delivered at the seabed. Unfortunately, 3D seismic surveys are extremely expensive and remain the domain of a few large multinational survey companies delivering data to client lease-block holders. Nevertheless, the high resolution, near surface data is proving invaluable to the government research program and the GSC Atlantic has been proactive in partnering with industry to access these data. This trend must be continued

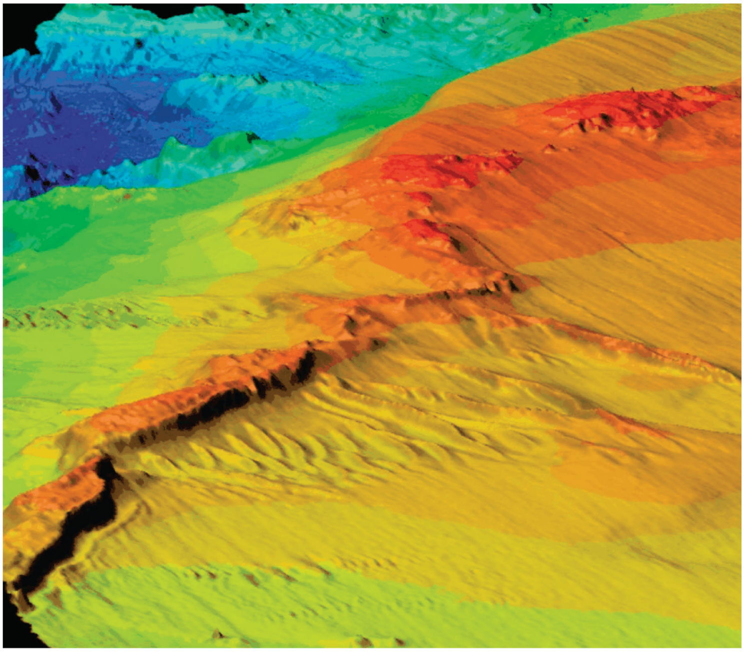

Fig 1 Oblique view of the Fundian Moraine, Browns Bank, Scotian Shelf. Field of view approximately 8 km. Water depth on top of ridge is 30 m. Multibeam mapping reveals that the Fundian Moraine is a complex feature composed of interconnected, lobate morainal segments, breached in places by low-relief sea floor. The flat top of the moraine suggests that it was subjected to erosion during sea level rise (Todd et al. 1999).

and placed on a more formal foundation in the future. In addition, there is a need for improved high-resolution seismic data, which will require systems with a deep-towed receiver and potentially a deep-towed source. AUV's may develop as the platform for such data acquisition.

As our ability has improved to image the seafloor accurately and with precise positioning, the "groundtruthing" of this imagery has moved away from textural analyses of discrete bottom samples toward characterisation by bottom photography and videography. Seafloor targets can now be re-visited with pin-point accuracy. Technological developments with low-light imaging systems and digital storage and manipulation of images means that there are new opportunities for direct seabed imaging ("photography" or "video"). Multibeam bathymetry provides horizontal resolution on a scale of metres: for many issues related to sediment transport and benthic habitat, resolution on a scale of centimetres is required. Digital imagery, combined with distribution of map products and data bases through the web and on computer disc enables photographs and video clips to be incorporated directly into these new products. Despite shared camera and video equipment between DFO and NRCan, the focus on shelf research over the last 20 years has been at the expense of the deep water studies. Research on slope geohazards, The Gully, and deep-water corals has been constrained by an inability to collect quality imagery beyond water depths of a few hundred metres.

No direct samples of sediments and rocks more than a few metres below the sea floor are available off eastern Canada, except for cuttings and sparse cores in areas of petroleum exploration (these make up only a small proportion of the Canadian offshore territory). Only one Deep Sea Drilling Project/Ocean Drilling Program sites is located within the 200-mile limit off eastern Canada (Site 645 on the Baffin Slope), with one other (Site 111 at Orphan Knoll) potentially within Canadian territory under UNCLOS and Site 384 on the J-Anomaly Ridge not far beyond the limit. This contrasts with tens of sites off the USA, France, the UK, Brazil, Japan, New Zealand and Australia. The geological framework of the Canadian marine territory is thus largely interpreted from remote-sensing geophysical data, except in well-drilled hydrocarbon basins. Sea-floor drilling is needed to provide basic knowledge of rock distribution beneath the continental margins, reference stratigraphic sections for hydrocarbon basins (analogous to the US COST program of the late 1970s), information on paleoclimate and past glaciation adjacent to Canada, and an understanding of the risk of catastrophic, deep-seated slope failure. The cost of such drilling will require a consortium approach, and include industry, government and academia, and probably also international partners.

Canada, with the longest coastline in the world, has always been a centre for research in remote sensing and application of these techniques to geoscience. High resolution photogrammetry has been the foundation for both coastal mapping and long term monitoring of major shifts in coastline position. Coastal surveys have always been labour intensive and reliant on sparse profile data. Kinematic GPS, and the increasingly higher resolution and broader applications of satellite remote sensing are beginning to transform coastal research, providing the opportunity to deliver greater geographical coverage, higher resolution and affordable repeatability.

In oceanography, a trend internationally has been toward establishing seabed observatories, or long term monitoring opportunities. The benefits to operational oceanography are obvious, but are equally significant in advancing our understanding of seafloor processes. Canada has acknowledged these directions with the recent announcement (by the Canadian Foundation for Innovation (CFI) and the BC Innovation Fund) to fund the US/Canadian "Neptune" and "Venus" projects on the Pacific margin, and Natural Sciences and Engineering Research Council (NSERC) and CFI sponsored observatories on Vancouver Island, the South Shore of Nova Scotia and on the west coast of Newfoundland. Such observatories provide long term time series of the state of the seabed and real-time observations of extreme events. To date, such observatories have been driven by the university sector, but they also provide great opportunities for government laboratories to get involved. They also have direct relevance to many industry issues (the state of stress and pore pressures in slope areas with historic landslides; the transport of seabed sediment). Offshore production platforms may provide an opportunity for short cabled links to specialised seabed observatories.

Globally, geoscience research is in the midst of a digital revolution. As an example, at the GSC Atlantic, digital data bases have largely been populated over the last six years and have matured to the state of being operational and on line. Canada's national marine geoscience repository contains information from over 1100 cruises, and more than 18000 cores. The next phase in this evolution to a digital world is to produce value added products and "knowledge" disseminated on line to all Canadians. "Basin", the GSC Atlantic hydrocarbon data base, currently provides this functionality. Digital atlases, containing raw data, photographs, mosaics, seismic lines and interpretive map products and text, are now becoming standard. The digital medium provides flexibility to tailor products to specific requirements, yet at the same time delivering within evolving national and international standards. Integrated management of Canada's oceans in the 21st century calls for the seamless integration of data and knowledge from all government agencies contributing to ocean management. This is one of the objectives of the Marine Geospatial Data Infrastructure Program of Geoconnections. At a local level DFO (Science, Oceans and CHS) and NRCan are co-funding research to integrate data within the East Scotian Shelf Integrated Management Plan (ESSIM). The architecture is largely in place to make digital geoscience information readily available to the public. Effort is now required to complete populating the data bases, apply adequate quality control over this data, generate new interpretive map products, and integrate the geosience data with other marine data bases.

LESSONS FROM THE INTERNATIONAL COMMUNITY

At first sight, the major emphases of the international community in marine geology are rather dissimilar from the pressures in Atlantic Canada. That was perhaps the same as in the mid 18th century, when recognition of the "Telegraphic Plateau" and the prescient observation that "it extends around the Earth as a Ridge" (Maury 1859) only became of direct relevance to Atlantic Canada with the development of plate tectonics more than a century later.

Prediction of the magnitude and effects of future climate change is the major societal issue currently being addressed by the international scientific community. Although in Canada, emphasis is on mitigation and adaptation to the impacts of climate change, many international studies are using the paleoceanographic record to understand the style and linkages involved in past rapid changes in climate. These involve (1) decadal variability in the Holocene, for which there is a record in eastern Canadian fiords and which may be related to changes in the Earth's magnetosphere (St.-Onge et al. 2003); (2) changes into and out of past interglacials; and (3) studies of major warm events in distant geological time, such as the Paleogene Thermal Maximum. The fact that the middle of the 21st century will see an insolation minimum underlines the importance of understanding complex climatic linkages, given the lack of significant predicted warming in Newfoundland and Labrador.

The integrated understanding of sediment transport in the world ocean (from source to sink) is the marine geology focus of the US Margins program (http://www.soest.hawaii.edu/margins/SedStrat.html) and is a successor to the STRATAFORM project and is complemented by EUROSTRATAFORM. Studies of this type have been concerned with processes in large scale river-fed sedimentation systems and the resulting deposit architecture and are of direct relevance to past sedimentation on the continental margin off Atlantic Canada and the evolution of petroleum basins. New insights into marine sediment transport processes arising from such studies should be directly applicable to Atlantic Canada.

The Integrated Ocean Drilling Program (IODP) (http://www.iodp.org/isp.html) initiated in 2003, has identified three key science issues that can be solved by drilling in the oceans: the deep biosphere in the sub-seafloor ocean; environmental change (in the ocean), processes and effects; and solid Earth cycles and geodynamics. Such long-term science is likely to be addressed more by universities than by government scientists in Canada. Unfortunately, Canada has not yet found a way to fund on-going membership of IODP.

Other international science issues have more direct resonance with issues in Atlantic Canada. The stability of continental slopes is a major issue world wide (http://otrc.tamu.edu/Pages/B119.htm), both because of its significance to seafloor hydrocarbon production facilities and trans-Atlantic cables and because of the far-field risk of tsunamis generated by slides on continental slopes (such as the 1929 Grand Banks event, which killed 28 people in southern Newfoundland) or on volcanic islands (Ward & Day 2001). The application of geological habitat mapping to better management of the diminishing world fisheries resource, work pioneered by industry and government in Atlantic Canada (Kostylev et al. 2001), is now receiving worldwide attention. For example, the European Union recently announced major funding for "HERMES" (Hotspot Ecosystem Research in the Margins of European Seas) (http://www.eu-hermes.net/), an international multidisciplinary program designed to provide new insights into the biodiversity, structure, function and dynamics of ecosystems and their natural environment along Europe's deep ocean margin. Environmental quality studies in inland seas such as the Baltic and Mediterranean seas as well as the coastal zone are providing methodology and concepts applicable to areas such as the Gulf of St. Lawrence and the St. Lawrence Estuary. Major instrumented studies of beach systems (e.g. at Duck, North Carolina (Birkemeier et al. 1985) and in the Netherlands (Ruessink et al. 2000)) will provide new understanding of beach dynamics and hopefully lead to stronger predictive ability in coastal engineering of beach systems.

The international marine geoscience research community is small and shares common problems in conducting research in severe environments. The community in Canada benefits from strong international links, to both colleagues and institutions, enabling timely gathering of intelligence, and timely adoption of new techniques, resulting in cost effective state-of-the-art research being conducted in Atlantic Canada.

WHAT WILL BE THE CONTRIBUTIONS OF GOVERNMENT MARINE SCIENCE TO MARINE GEOLOGY OVER THE NEXT DECADE?

One of the unquestionable strengths of marine science in Canada was the visionary decision in the 1960's to create multi-disciplinary research institutes first as the Bedford Institute of Oceanography (BIO) at Dartmouth and later the Institute of Ocean Sciences (IOS) at Sidney BC. The benefits of co-location of scientists, sharing equipment, platforms and workshops, has created a critical mass which established Canada as a world leader in oceanographic research. Financial cutbacks have strained working relationships, but the need today for interdepartmental collaboration is greater than ever. Much of the basic understanding of the marine science of Atlantic Canada has been gleaned from single discipline studies. However, many of the challenges in the future require a more holistic understanding of marine ecosystems that necessitate research in multi-disciplinary teams. For this to succeed a paradigm shift is required to move away from establishing research priorities within the silos of individual departmental mandates to recognising national and federal priorities in marine science and developing cross departmental funding mechanisms to deliver the required programs.

The requirements to deliver knowledge to implement Integrated Ocean Management has led several countries to develop programs to systematically map offshore territories. Ireland is midway through a survey program, the Norwegians have recently funded the "Mareanos" program to map their central coast, the Australian government has established a National Oceans Office, which among other tasks will establish mapping priorities. In Canada, successful collaborative pilot mapping projects between DFO and NRCan led to funding for cross-country consultations to develop a national strategy, "SeaMap", to map Canada's offshore lands. This strategy will form the basis of ongoing mapping programs in Atlantic Canada. Geoscience surveys and habitat modelling have been central to establishment of MPAs such as The Gully, and to the development of management plans for LOMA, such as on the Eastern Scotian Shelf (ESSIM). These pilots are precursors of the application of mapping to underpin Canada-wide management strategies in the future.

The last 15 years has witnessed major changes both in Canada and globally in the approach of governments to geoscience and oceanographic research. While each country has responded differently, the cycle in the western world has been common: cut-backs in support of federal programs in response to economic difficulties, divestiture of programs that might be considered completed or no longer relevant, and redefining programs to be closer aligned with government short-term priorities. The most successful laboratories (e.g., Southampton Oceanography Centre – UK, NIWA – New Zealand) have been those with the flexibility to respond to emerging priorities and a demonstrated relevance to national needs. Within this context, one of the greatest challenges is to balance delivery of immediate short term objectives with longer term strategic research needs, at the same time maintaining a balanced national program. The GSC has responded well to these challenges: following a 35% cut in resources through the mid 1990's, new opportunities for applying marine geoscience have been grasped. For example, international leadership has been applied to geoscience for habitat mapping and integrated ocean management; creative partnerships with industry enabled acceleration of research on the emerging frontier of the Scotian Slope to meet regulator and industry needs; an interdepartmental team, involving all levels of government, evaluated impacts of sea level rise and developed adaptive strategies for coastal Prince Edward Island; and the GSC played a leadership role in Canadian participation in the Ocean Drilling Program. Relevance to the Canadian public continues to be cemented through partnership and delivery of successful programs.

The GSC has realigned and redefined research programs across Canada. Within this framework, marine geology is strongly aligned with objectives of the "Geoscience for Ocean Management"(GOM) (http://www.gom.nrcan.gc.ca) and "Climate Change" Programs. With central themes of geohazards, integrated ocean management, marine environmental quality, habitat mapping and sea level rise impacts these national programs are clearly aligned with the research needs of Atlantic Canada and will provide the cornerstone for future research directions.

WHAT ARE THE CONSTRAINTS TO MAKING THESE CONTRIBUTIONS?

A number of structural social and political factors make the task of meeting these future scientific challenges more difficult. There is no effective national science policy on the oceans, within which government and university research priorities can be established. In the last decade, the government has moved away from funding core programs to supporting targeted initiatives, cross-cutting research and industry sectors. While this approach may diminish the fragmentation of the university sector in marine geoscience, it exacerbates the problems of developing a national geoscience research strategy. The GOM Program is NRCan's response to align research with government priorities. The Canada Oceans Action Plan (COAP) announced in the 2004 Speech from the Throne, represents a concerted effort to consolidate government ocean activities and provide focus for ocean management and research, cutting across departmental and sectoral silos. The shift in resources from government laboratories to universities in the 1990's, without any significant shift in responsibilities, has made recruitment of talented staff more difficult.

The age structure for professionals in government science organisations (and to a lesser extent in universities) is highly skewed towards the older age brackets. Recruitment of government scientists to replace those retiring will thus be in direct competition with not only Canadian universities, but also industry and international employers who are increasingly looking for geoscientists with marine experience. Strong strategic vision and increased resource levels will be necessary to make government laboratories the "workplace of choice" and to maintain their traditionally high scientific standards.

The age structure of infrastructure for marine geoscience parallels that of the scientists. It appears likely that the CCGS *Hudson*, the only blue-water research ship for Canada's Atlantic territory will still be in operation at age 50. Other vessels in the DFO fleet have been laid up over the last decade, creating pressure across marine sciences for available ship time. There is no low cost continental shelf research vessel on the Atlantic coast and no research vessel capable of handling the Canadian deep water Remote Operated Vehicle (ROV), "ROPOS". Historically major advances in marine geoscience research in Atlantic Canada have been driven through investment in technology, both in the laboratory and at sea. Many of these tools are aging, reinvestment in equipment is inadequate as national capital expenditures for science have been diverted through the CFI to the university sector. Attempts to pool marine geoscience equipment have failed (http://www.geoscience.ca/papersandreports/marinegeo.html): a new model for university - government laboratory cooperation is needed.

Industry is perhaps the most demanding of the clients for government science. Industry has greater flexibility and an ability to shift resources that is not matched in government, which therefore finds it hard to keep up with industry demands. New models of cooperation are needed with both industry and other government departments. The government will probably never be in a position to acquire new data such as 3D seismics and bore holes. As the oil industry moves from exploration to production the government needs to position itself to partner with companies, bringing regional expertise and complementary data to the table. The exploration industry is cyclic; during periods of downturn such as the 1980's, staff was released and many companies lost valuable expertise and most importantly valuable data. With the resurgence in offshore activity in the late 1990's, most of the major oil companies had no in-house capability and relied heavily on the GSC expertise and data as they rebuilt capacity.

Future advances in marine science will become increasingly cross disciplinary as traditional boundaries between disciplines are breaking down. Marine geoscience is recognised as one of the cornerstones of habitat mapping and ecosystem based management. The concept of geoscience playing a significant role in management of living as well as non-living resources is a novel one for NRCan, but has been acknowledged and resourced as a government priority under the new GOM research program. However despite this progress, government science is delivered within individual departmental mandates and the opportunities and funding mechanisms to develop truly joint interdepartmental programs requiring resources from several departments are rare. Changes in the federal perspective on oceans research are required at senior levels within government departments to develop priority research areas for Canadian's that cross departmental mandates; this needs to be matched with an appropriate funding mechanism.

CONCLUSIONS - THE CRITICAL ISSUES

The editor of this series asked that we identify the major scientific problems of the coming decade and describe the impacts of solving these problems, but also the consequences of not solving them. The two priorities for government marine geoscience over the next decades are: (1) seabed mapping for ocean management including safe and sustainable use of natural resources; and (2) societal responses in the coastal zone to natural hazards, global climate change and anthropogenic pressures. The general field of environmental quality and sensitivity is likely to become increasingly important, as public awareness of environmental degradation continues to develop, in part through the proactive stance of Non-Governmental Organizations (NGOs).

To deliver these programs will require a strong Canadian science program (involving universities, industry and government) in the history of glaciation, sediment transport processes, numeric modelling (particularly of coastal zone changes), and estuarine studies and an increasingly multidisciplinary approach. New field tools will be needed, notably research vessels, an AUV, improved high-resolution seismic equipment and seafloor camera systems, and research boreholes. Improved methods will be required to deal with large volumes of data (particularly multibeam bathymetry and backscatter) and to deliver research "knowledge" to users. Canadian scientists will need to maintain and strengthen links with the international marine geoscience community in order to fill numerous gaps in the Canadian marine geoscience program.

The major population centres of Nova Scotia, Newfoundland and PEI are all located in the coastal zone, which is of great economic importance to the region and susceptible to natural sea-level rise. The economic costs of mitigating the impacts of global warming and environmental degradation can be minimised by a clear understanding of the scientific issues (as, for example, the Dutch investment in hydraulics research supported the widespread land reclamation in that country). The complexity of the modern way of life and the pressure that population places on our natural environment requires that decision- making be firmly founded in scientific understanding.

Marine areas adjacent to eastern Canada make up 30% of the Canadian territory. The 20th century is littered with examples of unconstrained development and inadequate planning leading to poor decisions and adverse environmental impacts on ocean systems. The 20th century witnessed an unprecedented depletion of marine ecosystem diversity and quality. Economic and environmental consequences have often been severe, such as the collapse of the ground fishery in Atlantic Canada. Recognition of the emerging role of high resolution marine geoscience in ocean management provides a fundamental new rationale for the GSC to support sustainable management of the living as well as the non-living resource. Within the global paradigm shift toward integrated ocean management marine geoscience has a responsibility to not just contribute to, but also lead integrated research underpinning the delivery of sustainable and precautionary management of our oceans.

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