

# Marine Geoscience Contributions to Integrated Coastal Zone Management

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## Introduction

Coastal environments worldwide are subject to increasing pressures from rapid population growth and diversifying resource use. At the same time these environments experience variations in natural processes, over wide magnitude and frequency scales, for example from short duration, high intensity storms to long term relative sea level fluctuations.

Strategies for sustainable resource development involve the management of coastal regions, including the design, construction and maintenance of the required development infrastructure. The World Coast Conference (1993) defines Integrated Coastal Zone Management (ICZM) as involving the “comprehensive assessment, setting objectives, planning of coastal systems and resources . . . a continuous and evolutionary process for achieving sustainable development”. “Sustainable” development means that there is a specific commitment to the management of coastal regions and resources in an environmentally responsible manner. The preservation of environmental quality for future generations involves remediation of past deleterious development impacts, and taking informed decisions to reduce future adverse effects and, where necessary to define and acknowledge risk.

An important basis for sound policy decisions and plans is scientific information. A recent (1992) Ocean Studies Board report on ocean policy asserted that “to the extent that such policy decisions are to be useful, they must be consistent with the best available information about how the whole system works: its physics, chemistry, geology, and biology.” But a 1995 National Research Council report on ‘Science, Policy and the Coast’ also suggested that improvements are needed in the interaction between natural and social scientists, and policy makers/implementers at all levels, because there are examples of failures where scientific knowledge was not used.

In this regard different scientific disciplines and science agencies have a responsibility to clearly identify their conceptual, database, and technological contributions to ICZM, as well as the potential for multidisciplinary synergies and linkages. The following discussion seeks to illustrate some of the principal contributions that marine geoscience in general, and Canadian marine geoscience specifically is making to ICZM, and to indicate some future directions of the Geological Survey of Canada’s marine program.

## Coastal Systems

In functional, planning and scientific terms, coastal areas must be considered

complex systems involving interactions between natural and socio-economic development components (Van der Weide 1993, der Vrees *et al.* 1995). A holistic systems approach facilitates identification, measurement and modelling of system behaviour, particularly giving attention to the interactions between natural and socio-economic factors (Fig. 1). The socio-economic development plans for a coastal area include the user functions of food production, energy supply, water supply, housing and recreation, as well as development of industrial and economic activities. These user functions are accompanied by the need for physical infrastructure (eg. communications arteries, harbours, dams) and institutional infrastructure (eg. political, legislative and financial systems).

In relation to ICZM der Vrees *et al.* (1995) describe the natural system component as comprising all non-human aspects, such as air, water, sediment and marine

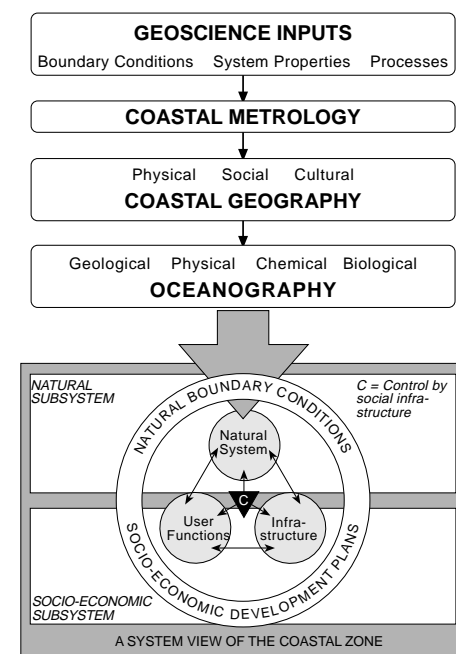


Figure 1: A system view of the coastal zone and the role of geoscience in coastal zone management (modified after Der Vrees and Van Urk, 1995).

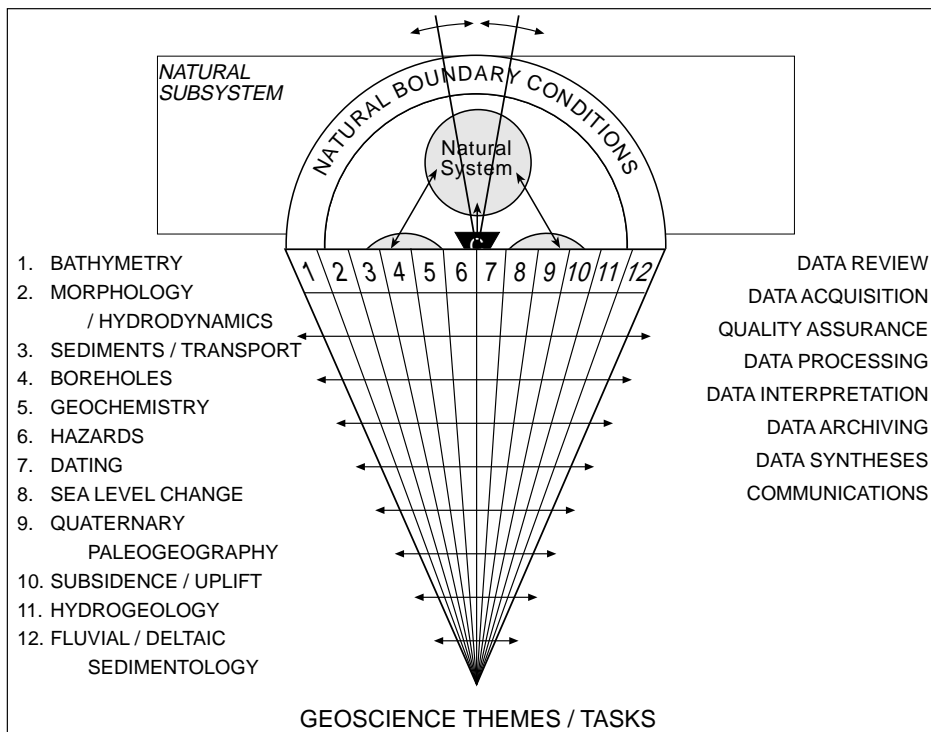


Figure 2: Thematic geoscience knowledge and data management required for effective ICZM.

biology involved in complex dynamic interactions (aerodynamic, geodynamic, hydrodynamic, morphodynamic and eodynamic). The natural component can be also be further subdivided into:

- natural boundary conditions (such as relative sea level contexts, or climatic regime)
- system properties (such as coastal bathymetry, sediment type, storm frequency, renewable biologic resources and non - renewable mineral and energy resources)
- system processes (such as sediment transport, or tidal water circulation mechanisms)

It will be readily apparent that such a complete treatment of the natural component of coastal systems (Fig. 1) requires combined knowledge from several natural sciences such as oceanography (physical, chemical, biological and geological), coastal geography, and climatology/ meteorology. In some organizations these disciplines are grouped most broadly as “geosciences”, whereas in others geoscience refers specifically to geology, geophysics, and physical geography.

Whether the definition of geoscience is specific to certain natural science disciplines, or inclusive of many, it is clear that the natural system approach needed for ICZM requires substantive knowledge of the characteristics, origins and behaviour of marine and coastal rocks, sediments, processes and landforms (Figure 2). Baseline knowledge of these components of coastal systems will facilitate ICZM because they contribute fundamentally to:

- the identification of non-renewable resources and their potential for development
- the recognition and definition of potential impacts of development on the environment, both in terms of human health and safety and habitat protection
- the recognition and definition of constraints and hazards to development, particularly in terms of human safety and engineering risk
- the understanding of the differences between natural environmental changes and those induced by human activity, through the definition of baseline environmental conditions and monitoring of changes.

## ICZM and the Geological Survey of Canada

Under the newly introduced Canada Oceans Act, the Department of Fisheries and Oceans (DFO) will have a national leadership role in ICZM. It is also recognised that other agencies, at various levels of government, have mandates and capabilities in coastal and marine science, technology and management and will contribute to emerging plans for ICZM on national and local levels. For example, the Department of Natural Resources (NRCan) and its Geological Survey of Canada (GSC) is the major source of coastal marine geoscience information for Canada, with a comprehensive national science program involving projects in the Atlantic, Pacific and Arctic Oceans, and in the Great Lakes. The program is delivered by two divisions: GSC Atlantic located at the Bedford Institute of Oceanography (Dartmouth) and GSC Pacific, at the Institute of Oceanographic Sciences (Sidney). These interagency Institutes facilitate shared technical and scientific resources and joint projects, principally between DFO and NRCan (GSC). Recognising that ICZM can only be successful through multidisciplinary collaboration it is apparent that new momentum in ICZM in Canada will further strengthen existing relationships between DFO and NRCan, as the Geological Survey’s marine program continues to provide new geoscience knowledge of Canada’s coastal and offshore regions.

## The Geological Survey of Canada’s Marine Geoscience Program

Canada’s coastal and offshore territories comprise almost 40% of its total landmass, and contain proven, valuable hydrocarbon, mineral and biological resources. Canada has one of the longest coastlines in the world, bordering the Atlantic, Arctic and Pacific Oceans, in addition to the Great Lakes coastal areas. Large areas of Canada’s offshore are not adequately mapped to modern standards, territorial limits not completely established, the resource potential is poorly defined and environmental knowledge is lacking. The GSC’s new marine geoscience information serves wide clientele of marine-based resource and en-

vironmental industries, and other federal and provincial agencies with related science or management mandates.

The GSC's marine program addresses problems and needs for geoscience information, generally on a regional or process mechanism basis, for subsequent site-specific exploitation by industry, or for problem solution by task-specific agencies. GSC marine projects use specific site locations to conduct process experiments or as demonstration areas for new capabilities.

The program delivers scientific concepts, data bases and state-of-the-art interpretive maps of Canada's coasts and sea floor. The information is used by industry (e.g. oil and gas, survey, telecommunication, engineering firms) for resource assessments, initial development site selection, detailed site investigation decisions, and regional evaluation of development problems. Moreover the GSC's marine program products find utility, at all jurisdictional levels, in the development of governance strategies for resolution of multiple use conflicts, environmental protection and industrial development - all important components of ICZM.

The program's operational plan simultaneously addresses Canada's present and future needs for ICZM information on marine resources and environments. Flexible program implementation facilitates choices in resource deployment to serve high priority, immediate, national and local needs, such as the present focus on coastal, nearshore and lake areas with high population and development pressures. A phased, opportunistic approach (2-5 year time frame) allows modest efforts in remote regions. For example, Arctic and deep water work, truly unknown areas in terms of Canada's resource base, uses joint venture projects with other nations, with shared technical and ship resources. Medium term (5 plus years) research into marine resources, for example frontier deep water oil and gas, and hydrothermal minerals, anticipates changes in economies and technologies of production. Long term (5-10 years) research into fundamental properties of Canada's margins and offshore territories provides basic understanding of process origins of continents and contiguous basins

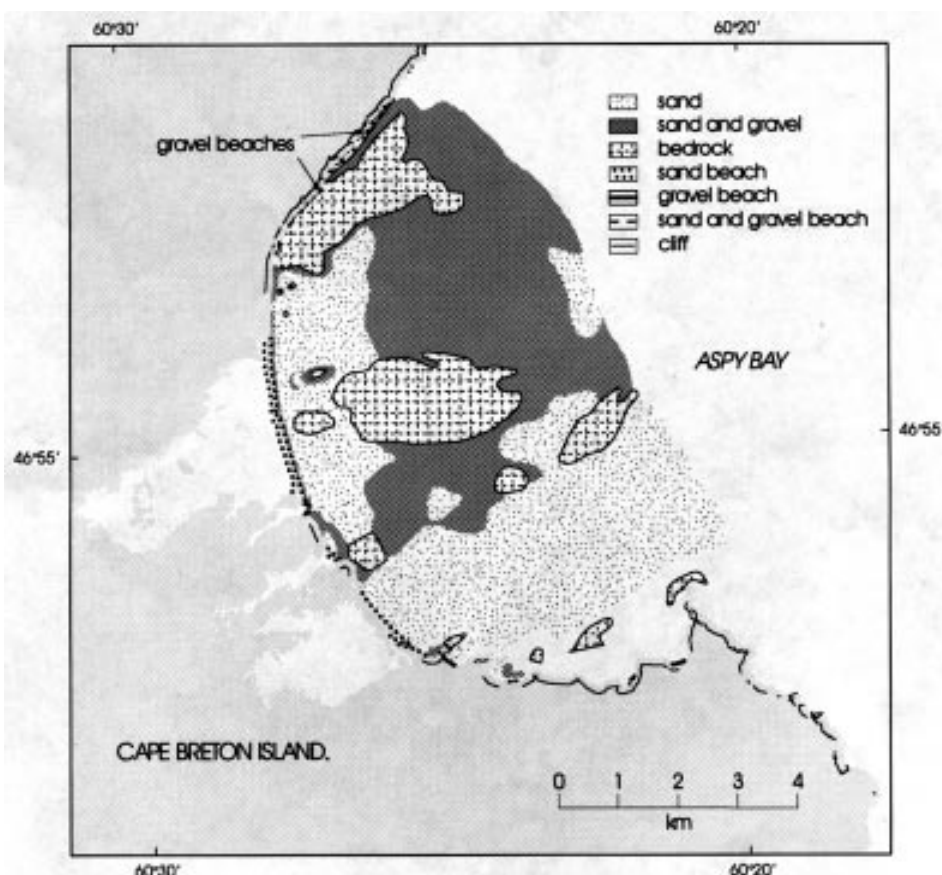


Figure 3: Surficial geology of Aspy Bay integrated with selected features from the GSCA Coastal Information System.

for resource modelling, and an understanding of paleoenvironments for climate change models.

The GSC marine program is organized into three main thematic components:

- **Regional Geoscience** - acquires baseline geological and geophysical data at a variety of scales, seeking new concepts of continental margin evolution, including plate boundary processes, spreading ridges, and basin development. The work includes broad regional geophysical compilations for refinement of global, regional and local scale models of margin evolution, seeking linkages between margin development and the basins they contain, contributing to new hydrocarbon and mineralization resource models.
- **Resources Geoscience** - pursues the identification, understanding and assessment of non-renewable resources in Canada's coastal and offshore areas. The present focus is primarily towards offshore oil and gas, with some interest in offshore minerals, and emerging needs for geoscience aspects of biological habitats. Coastal mineral resource potential is beginning to be assessed using state-of-the-art seafloor mapping technology, which is also being applied to benthic fisheries habitat evaluation.
- **Environmental Geoscience** - seeks understanding of natural geologic processes which affect development of coastal and offshore resources, and evaluates potential or previous impacts on the environment by development. This program provides the geoscience knowledge essential to understand and solve marine and coastal environmental problems, using a combination of mapping and process studies along with capabilities in sedimentology, geochemistry, paleo-

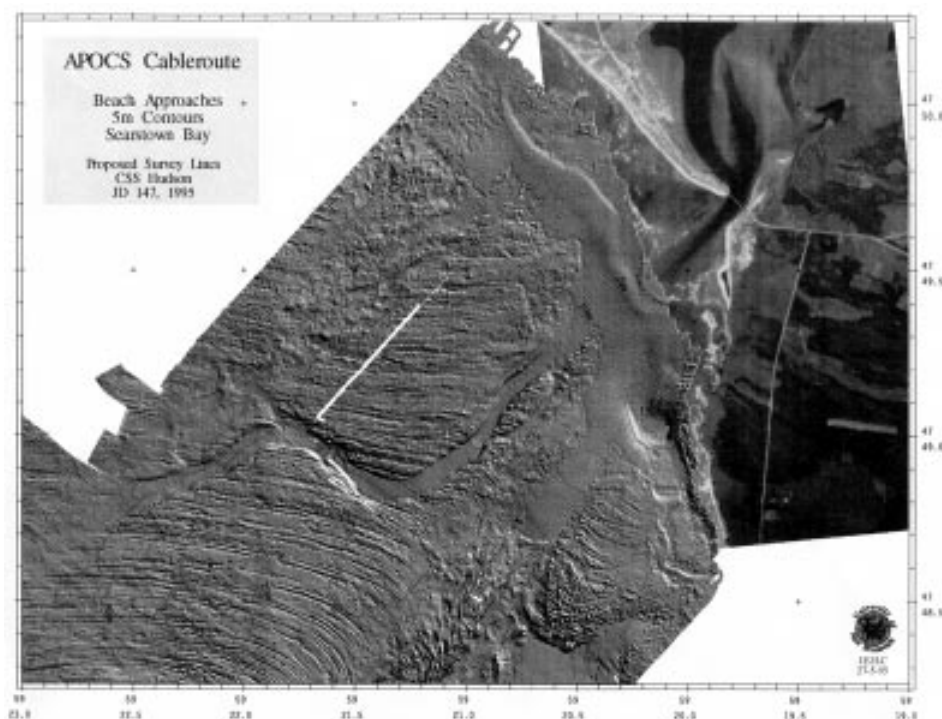


Figure 4: Bathymetric chart compiled from multibeam data of the proposed APOCS cable route landing site in Searstown Bay Newfoundland. The seafloor is largely exposed bedrock, incised by a sediment filled relict river channel cut during a period of lower sea level. The channel provided an ideal conduit in which to protect the cable.

environmental reconstructions, coastal dynamics and geotechnical engineering. The program combines basic and applied research elements to address a broad range of problems on environmental or developmental issues, from waste disposal to offshore hydrocarbon production engineering. For example there are efforts to refine understanding of the distribution, magnitude and frequency of marine geologic hazards, such as seabed erosion, fluid escape, ice/sediment interactions, neotectonics and submarine landsliding. The definition of processes and mechanisms facilitates risk assessment and constraints to construction of coastal and offshore engineering structures and sea bed installations such as jetties, platforms, pipelines and cables. Sedimentary signatures of past process activity are interpreted in magnitude frequency terms and to discriminate natural and anthropogenic events. High resolution paleoenvironmental reconstructions from marine sedimentary records illuminate the types and rates of former natural climatic changes.

## Recent Research Relevant to ICZM

**Regional and site specific maps of coastal landforms**, with classifications usually representing a combination of feature process origins, landform geometries and sediment or rock types have been completed for high priority areas. Regional maps are commonly presented at scales of 1:200,000 or greater while more detailed site descriptions are at 1:10,000 or less. Reconnaissance mapping of Atlantic and Arctic coastal areas has been assisted by video photography from helicopters, in partnership with Canadian Coast Guard. Coastal videos of Atlantic Canada, released in a series of Open File Reports, have been used in combination with ground mapping, monitoring and process studies as the basis for erosion prediction, sensitivity analysis, and for spill contingency planning (Sherin *et al.* 1995). Increasingly coastal landform maps and the data which comprise them use GIS technology for standardization, data manipulation and to facilitate data exchanges. For example recent work has produced a Coastal Information System (CIS) to map coastal landforms utilising dynamic segmentation techniques in

ARCINFO (Fig. 3). Design and testing of the prototype is nearing completion and a data base being built with federal and provincial partners for Atlantic Canada. Increasingly, combinations of mapping technologies are allowing continuous coastal mapping from the land to beneath the sea. For example marine surveys are now possible into very shallow water depths facilitating combination with data from aerial video, airborne radar or satellite mapping technologies.

**Coastal and nearshore bathymetry** is a fundamental property of any coastal system and the data has direct application to a wide range of issues, from habitat definition, navigation routeways, harbour and jetty construction, waste disposal planning and, sea floor installations such as cables and pipelines, and is a basic engineering design parameter. Recently, multibeam survey techniques developed by the Canadian Hydrographic Service in partnership with the GSC have revolutionised bathymetric data acquisition and display, greatly enhancing coverage, survey rates, accuracy and visual display methods - in turn facilitating improved data interpretation and extending the usefulness of the data. Examples of recent high resolution coastal and nearshore surveys are provided by demonstration multibeam surveys over the APOCS cable route between Cape Breton and Newfoundland. GSCA multibeam mapping was able to delineate relict river channels cut across the continental shelf during periods of lowered sea level, providing a natural sediment filled

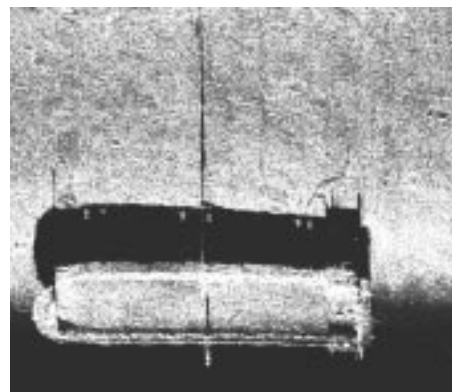


Figure 5: Sidescan sonar image of the wreck Irving Whale, sunk in 67m of water during a storm in 1970. Ships dericks, lines and other debris can be clearly identified. (After Parrott 1995)

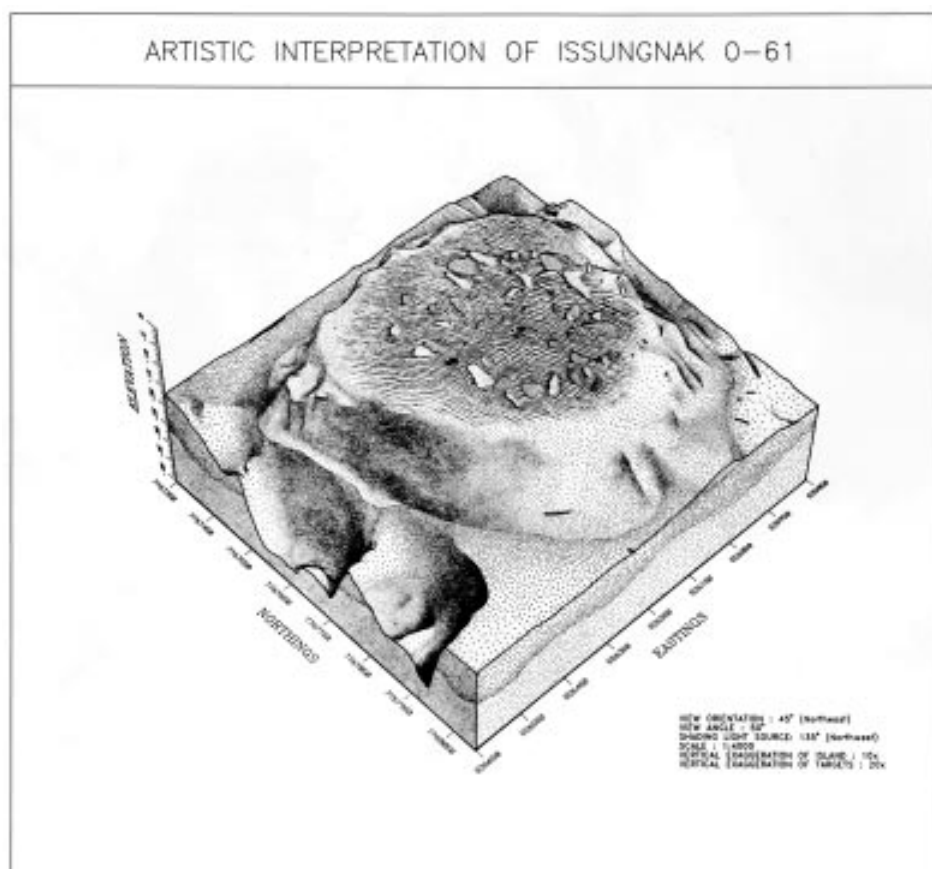


Figure 6: A scaled three dimensional interpretation of an abandoned artificial island in the Beaufort Sea. The borrow pit can be seen in the foreground, the eroding top of the island is littered with debris and active bed forms.

conduit for cable protection. (Josenhans 1995, Fig. 4).

**Sea floor imagery**, provides spatial data of bottom characteristics to complement water depth data. Typically geoscientists use sidescan sonars and multibeam backscatter systems to make mosaics of the sea floor. At GSC Atlantic both sea floor imagery mosaics and multibeam bathymetry surveys have been significantly improved by the increased navigational accuracy possible with DGPS positioning technology. Sea floor mosaics which can show the location of man - made objects such as shipwrecks, waste dumps, pipelines and cables also contain valuable information about sediment distributions (Parrott 1995, Fig. 5). The imagery also captures the signatures of a wide range of bottom processes such as current erosion and deposition, landslides, gas escape, and faulting - usually identified from specific bottom forms and morphologies. Demonstration of the application of this technology to ICZM has included:

- completion of a major geochemical study of the contamination status of sediments on the floor of Halifax Harbour, the recipient of centuries of urban and industrial effluent discharge. The project results contributed to decisions regarding the design and location of waste remedial and treatment measures (Buckley *et al.* 1992)
- mapping of anthropogenic waste at former military installations at Argentia and DEW line sites in the Arctic, and modification of artificial islands following abandonment in the Beaufort Sea (Fig. 6)
- partnering with Canadian industry to transfer multibeam mapping technology to the private sector through a demonstration survey for fibre optic cables linking Newfoundland and Nova Scotia.
- collaborative nearshore surveys with

Parks Canada to quantify and understand processes of coastal change within National Parks and heritage sites.

**Sediment properties** are fundamental factors in coastal zones - for example controlling and affecting the way in which coastal and nearshore areas change and evolve under natural conditions, determining the characteristics of different biological habitats, influencing the economic development of mineral resources, and providing limits and constraints to the design, installation and maintenance of engineering structures. As a recent example the GSC offshore mapping program provided the initial scientific framework for designing a federal and provincially funded project to evaluate aggregate potential on the Scotian Shelf. After two seasons mapping and sampling target areas, viable resources have been identified. Follow up laboratory testing is yielding information on the texture, mineralogical, geochemical and geotechnical attributes along with strength to determine suitability of the aggregate for industrial uses (Fader *et al.* 1994). *In situ* procedures are increasingly yielding important new information about the properties of sediments at and near the sea floor, such as porosity, pore fluids pressures, gas contents and shear strength, which affect other behavioural properties such as sediment stability and erodibility.

**Sediment budgets** are key factors predicting coastline and sea floor changes. For example, the effectiveness of different processes such as longshore drift is a function both of the hydrodynamic regime and the availability of sediment. Deltaic systems, where sediment input usually exceeds dispersal, are areas of coastal progradation, whereas erosion and retreat sometimes are related to a paucity of sediment supply. Recent work is showing that these relationships can be extremely complex with much to be learned about sediment inputs, transport, storage, and renewal, and their relationships with different process magnitudes. At the coast, sediment budgets are derived from long term monitoring of beach profiles, from which effects of storm magnitude and frequency can be determined. In the nearshore, seafloor mapping has been used to identify sources and

sinks of sediment and their effects on the sediment budget (Shaw *et al.* in press, Fig. 7). On the Scotian Shelf and Queen Charlotte Islands changes in the seafloor are more subtle, and hydrodynamic processes, sediment property and bathymetric data are combined to generate numerical box models of sediment transport, from which simulated sediment budgets have been developed and calibrated against field observations of coastal response.

**Coastal and sea floor processes** are the driving mechanisms in the coastal zone. Energy from waves and tides is transmitted to the seafloor and expended in eroding, transporting and redistributing sediments. In the geological time frame coasts are ephemeral features, forming, transgressing and reforming across the continental margin in response to sea level fluctuation, sediment supply and available energy. Understanding processes of sediment transport is fundamental to engineering design in the coastal zone including ports and harbours, coastal protection, cable and pipeline routing, and in developing predictive models of coastal response and in ground truthing sediment budgets. GSCA program in sediment transport has developed a unique suite of tools to monitor sediment dynamics. The stability of sandy sediments in high energy shelf environments has utilised RALPH, an instrumented tripod, to monitor sediment transport rate and direction (Li *et al.* in press Fig. 8). On the Scotian shelf predictive models of sediment transport and bedform migration have been developed and are being utilised by industry in planned development for off-

shore production facilities and pipelines. Estuaries, coasts and lakes have long been the repositories for man's waste. This is often untreated and is now being recognised as a major environmental concern. The ability of aquatic systems to absorb anthropogenic materials is being exceeded, the ecology under stress, and viability of ongoing sustainable development in jeopardy. Cohesive muddy sediments are the sink for man's waste. These sediments respond very differently to near bed stresses than sands and consequently require totally different tools to study sediment mobility. The annular flume, Sea Carousel, has been developed to measure bed stability *in situ*. Studies of immediate application to ICZM have been conducted on the stability of dredged and dumped sediments in Atlantic Canada and (in cooperation with Environment Canada) on artificial restoration of polluted sediments in Hamilton Harbour (Amos *et al.* 1996).

**Seafloor geologic hazards** constrain sustainable development in the coastal zone. The siting, construction and maintenance of engineering structures must take account of hazards such as erosion, sedimentation, landslides, gas and ice scour which, unless properly defined, can stop new engineering development. The GSC contribution to marine hazards research is largely funded through the PERD Program. The research emphasis is on quantifying processes and understanding hazard magnitude and frequency. This research provides the technical base for advising developers, environmental groups and regulatory agencies involved with engineering development in the coastal zone. Research of seabed hazards and constraints to coastal and offshore engineering is conducted in a wide variety of geologic settings, with an equally diverse range of hazards leading to innovative engineering solutions. Research activities presently include, Beaufort sea ice/permafrost effects on foundation conditions, effects of iceberg scour on seafloor sediments, submarine landslide assessments for cable routes crossing the Fraser Delta (Christian *et al.* Fig. 9), and evaluation of neotectonics activity from sedimentary structures in the Great Lakes.

**Vulnerability assessment** as defined by The International Panel for Climate Change

(IPCC) involves a "Common Methodology" to allow definition of a coastal nation's ability to cope with the consequences of global climate change, including accelerated sea level rise. The IPCC vulnerability assessment process offers one way for a coastal federal, provincial, municipal, or community agency to "review existing capabilities and performances in coastal zone planning and management" (World Coastal Conference. 1993), within the context of a long term approach.

The Common Methodology involves seven steps, and marine geoscience programs at GSC Atlantic make important contributions in at least three - the specification of accelerated sea level rise boundary conditions; the provision of natural system data; and the assessment of physical changes and natural system responses.

In much of Canada relative sea level change is a complex balance between isostatic rebound of the landmass following deglaciation and eustatic sea level rise due to changes in ice cap volume. It is possible to travel short distances along the shore and pass from emergent prograding coasts to submerged erosional shores. The understanding of these natural cycles of sea level change is necessary to place in context sea level rise induced by global warming. Relative sea levels histories from decadal through geologically recent (Holocene) times are reconstructed through analysis of tide gauge records, the changing shoreline geomorphology, drowned coastal landforms, and high resolution paleoenvironmental reconstructions from the coastal and nearshore sedimentary records.

In terms of vulnerability to sea level changes GSC Atlantic maintains an extensive coastal monitoring program to define recent changes in coastline behaviour on a regional basis and at specific coastal sites. These serve to indicate trends which when combined with analysis and modelling of changing storm intensities, allow projections of future coastline changes. This information is essential in defining protective buffer zones for inclusion in ICZM plans to guard against unwise development close to the shore. Different schemes have been used to map coastline changes patterns

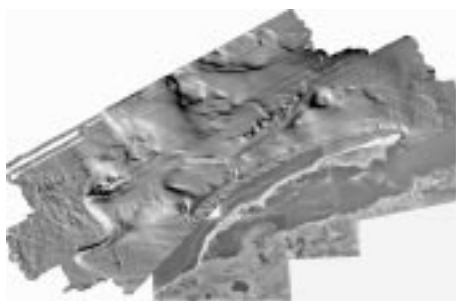


Figure 7: Multibeam swath image of ST Georges Bay Newfoundland. Shore-normal bedforms on the nearshore terrace channel sediment landward into deep water, feeding debris cones and withdrawing sediment from the coastal budget. (After Shaw *et al.* In press)

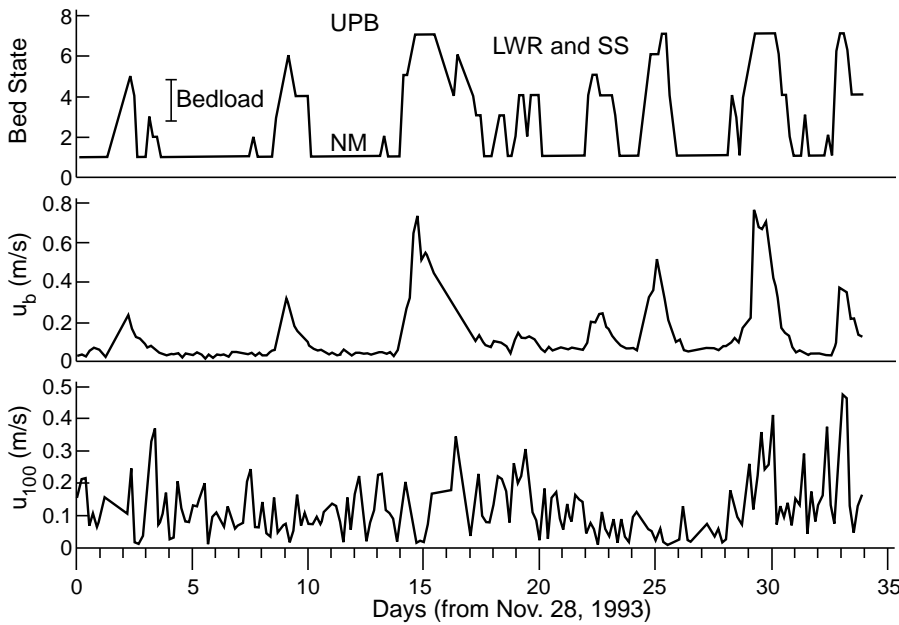


Figure 8: Time series plots of data from instrumented tripod RALPH installed on Sable Island Bank. Water depth ( $h$ ), mean velocity ( $U_{100}$ ), significant wave height ( $H_s$ ), spectral-peak wave period ( $T_p$ ), and sand suspension in transmission % at 33 cm above the seabed ( $C_{33}$ ). (After Li and Amos in press).

and responses to relative sea level fluctuations, and one example is provided by Shaw *et al.* (1994) synthesising available knowledge of sea level history and shoreline type to produce a coastal vulnerability map for the entire Canadian coastline.

including oil and gas reserves, and placer minerals. Synthesis, analysis and updating of existing databases will concentrate on areas where there is recent momentum in energy exploration and development such as

the Gulf of St. Lawrence, the Grand Banks and the Scotian shelf. A multi-disciplinary team project will commence focusing on the Gulf of St. Lawrence region.

- new Canadian technical capabilities in ocean mapping will be used to develop innovative applications and practices in scientific investigations of environmental problems, such as sea floor hazards, definition of seafloor habitat, pollution of marine sediments and dredging effects. The improved mapping capabilities will also be used for quantitative nearshore mineral potential, in anticipation of leasing legislation and production development.
- a pilot project will be initiated and completed in a severe land loss area of Prince Edward Island, combining mapping, monitoring, modelling in the coastal and nearshore zones as a basis for implementing a “type coast” system approach to other areas of Canada.
- ICZM needs will require further development of ICZM databases for

**Some Future Directions**

Within Canada demands for geoscience data for ICZM are expected to grow, from communities, municipalities, provinces and other government departments. The GSC Marine Program will continue to contribute the necessary geoscience information for ICZM through a balance, between baseline data acquisition, concept development, and application, supported by technology innovation. Major program objectives will continue to be the provision of marine geoscience information for non-renewable and renewable resources development in coastal and offshore areas, and for environmentally-responsible development decisions. Data will continue to be acquired for high priority areas defined with client consultation, but some overall program directions and initiatives are as follows:

- basic research will introduce new concepts relevant to the identification of non - renewable resources in coastal, nearshore and offshore areas,

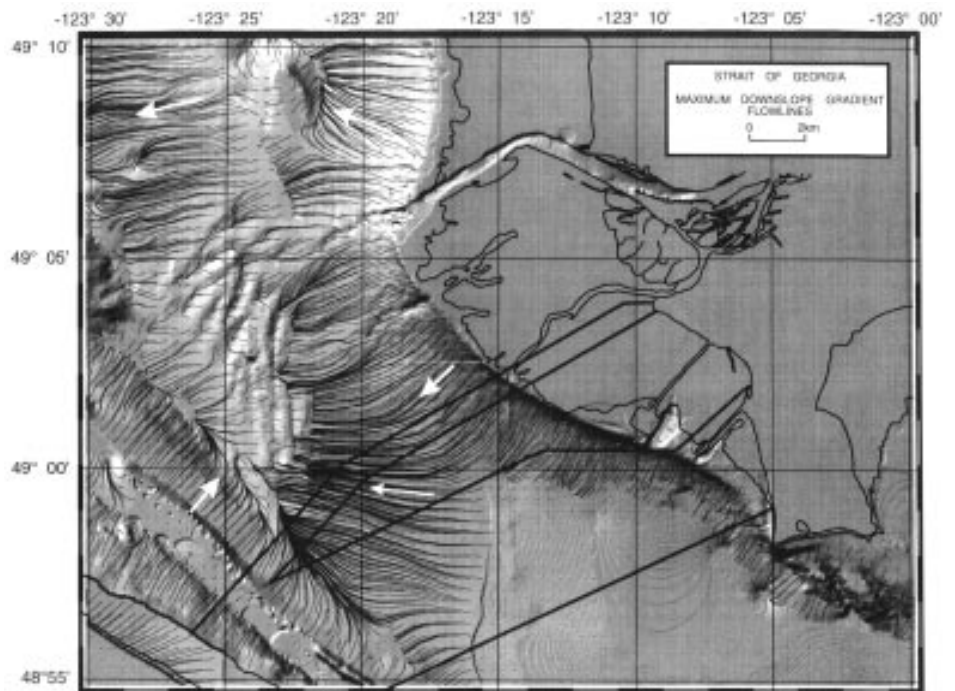


Figure 9: Maximum downslope gradient flow lines on the Fraser Delta, used to predict landslide travel paths. (After Christian. In press)

coastal areas, in formats suitable for wide user access.

- PERD program objectives in reducing the effects of geological hazards to offshore energy issues will continue to identify high priority areas for research into sea floor geotechnical properties and engineering process constraints, including Scotia shelf (gas platforms, pipelines), Fraser delta (electrical transmission lines) and Grand Banks (Hibernia spin off production facilities).
- new geoscience practice developed for Canada's coastal and offshore areas, will be shared with and transferred to Canadian industry, with the objective of wider global application, where there are increasing needs for geoscience information for ICZM. One objective will be the refinement of geoscience data acquisition and practice through demonstration projects in developing countries, in partnership with agencies such as the South Pacific Applied Geoscience Commission (SOPAC) and the Coordinating Committee for Coastal and Offshore Geoscience Programmes in East and South East Asia (CCOP).
- maintained participation in The Ocean Drilling Program will enable advances in understanding of paleoclimates, at high resolution time scales, relevant to sea level histories and characterisation of natural and man-induced environmental changes. For example specific studies of Canadian offshore sediments (eg. Saanich Inlet) will contribute both to local paleoclimatic reconstructions, and to global models.
- GSC marine environmental scientists will take a lead role in a new GSC-wide initiative on lakes research (including the Great lakes), using technology, skills and experience from existing projects in lakes Ontario and Winnipeg, and imported from other marine research themes. Established partnerships with local industries, other government departments, and neighbouring provinces will be specially focussed to new understand-

ing of issues such as lake pollution, shoreline stability, lakebed foundation conditions and hazards, aggregate mining, dredging and disposal, and cultural heritage site descriptions.

- NRCan is one of the proponents of a new interdepartmental Marine Environmental Quality Action Plan (MEQ). The GSC marine program seeks to cooperate with other participating federal agencies in initiatives in coastal pollution studies but will take the lead in selected projects, such as Vancouver Harbour/Fraser delta, where geochemical status studies can be linked to other GSC work in sea floor process studies such as sediment transport modelling.

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