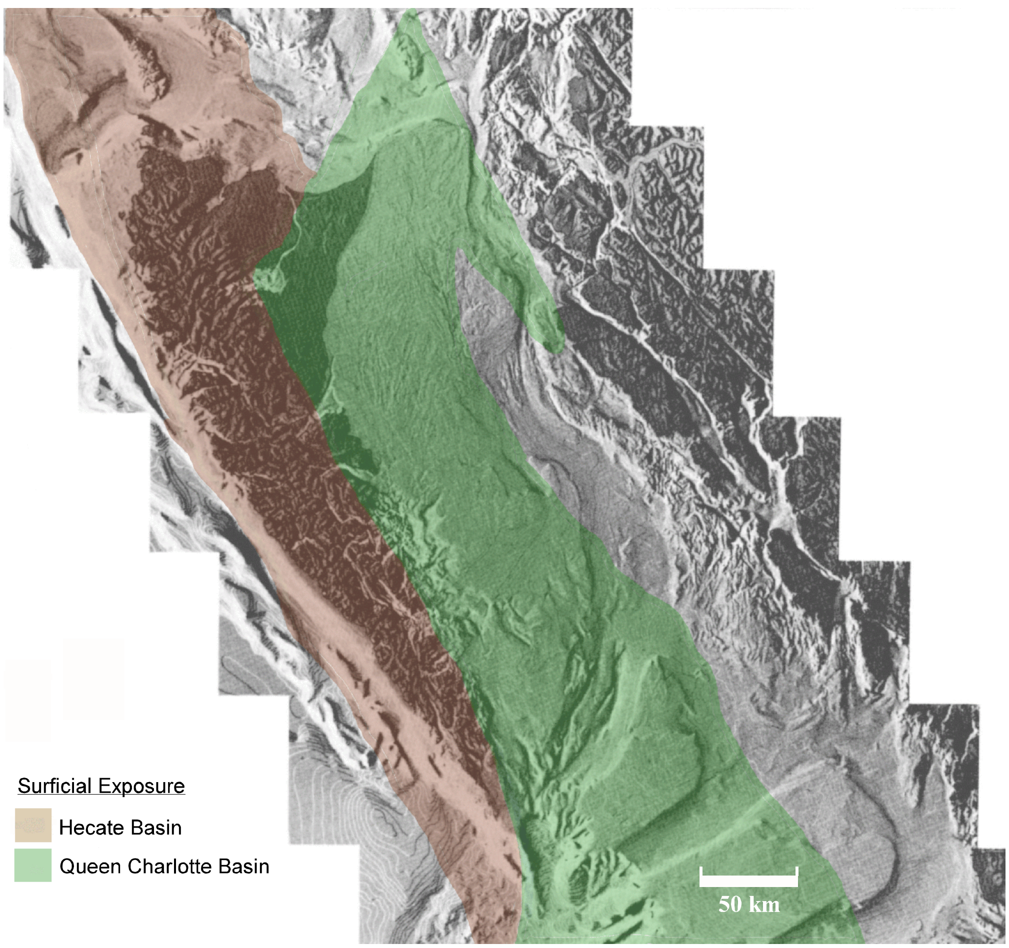
Potential Marine Geohazards in the Hecate and Queen Charlotte Basins



BRITISH COLUMBIA

Prepared for the British Columbia Ministry of Energy, Mines and Northern Development

Potential Marine Geohazards in the Hecate and Queen Charlotte Basins

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Executive Summary

More than ten years have passed since the British Columbia and federal governments carried out their last review of the moratorium on offshore petroleum exploration on the west coast. At that time a five-person panel federal - provincial was set up to hold public hearings throughout northern coastal British Columbia. Chevron Canada Resources Limited and Petro Canada were the industry proponents, but Petro Canada eventually withdrew. Both Chevron and Petro Canada submitted Environmental reviews at that time. The panel delivered a report on their findings to both governments in 1986. They recommended the lifting of the moratorium and provided 92 recommendations to help the two governments establish a Pacific Accord.

None of the earlier reports and submissions related to the moratorium provided sufficient information on geohazards, i.e. hazards related to geological processes, associated with oil and gas exploration and production and their impact on environmental issues and socio-economic conditions. Nor do the earlier reports discuss the methods available for mapping and characterizing these hazards. This information is essential for decision making on offshore issues.

Marine geohazards are not unique to the offshore of Western Canada. Indeed these hazards occur in offshore basins throughout the world, for example the North Sea, the Gulf of Mexico and the Niger Delta, as well as the East coast of Canada and the Beaufort Sea. Each basin has its unique set of hazards. For example, iceberg scouring is a present day hazard on the east coast (offshore Newfoundland) which is not present on the west coast. On the other hand large earthquake events are a significant potential hazard on the west coast.

The present study fills in this gap by focussing on the impact of geohazards on oil and gas exploration and development and on the technologies available for mapping seafloor and shallow subsurface features that can be used to identify these hazards. The report focusses on the Hecate and Queen Charlotte Basins as this is expected to be the main area of interest for any future offshore oil and gas exploration.

An overview of the oil and gas potential of these basins is given and an indication provided of what areas within the basins have the highest oil and gas potential. A review of potential geohazards for oil and gas exploration and development is furnished, along with a discussion of the methods available for mapping these features. Environmental and socio-economic issues within the Queen Charlotte region caused by the impacts from potential geohazards are provided.

The report further suggests that a pilot study be carried out within the Queen Charlotte region to demonstrate the approach used to map these potential hazards. The area was selected within the region where the oil potential is considered to be high. Moreover it was selected in an area where fishing activity, spawning grounds and marine sensitive areas are at high risk if a hazard occurs. The area was also selected where there would be enough sidescan, high resolution seismic, bathymetry and other information available to carry out regional mapping.

The pilot study is typical of the regional marine geohazards mapping carried out on the east coast by the federal and provincial governments. Regional geohazards mapping started in the late 1960's when hydrocarbon exploration first started and is still being carried out today. Industry has traditionally done detailed (site-specific) surveys for drilling wells and placing platforms. They have relied on the government surveys to provide a regional perspective. Government agencies have found these regional surveys of immense value for risk management of offshore and coastal environments. Based on the experience gained for the east coast, regional studies have provided the information needed for good decision making.

The conclusions and recommendations as determined by the report are;

o A high interest area for potential offshore exploration is located in southern Hecate Strait and northern Queen Charlotte Sound of British Columbia.

o Technology exists to map and identify any potential seafloor geohazards in the Queen Charlotte region.

o The high interest exploration area is located in important fishing and spawning areas. It also encloses and is surrounded by numerous sensitive areas, including ecological reserves, parks and marine protected areas.

o The data bases for bathymetry, high resolution seismic, sidescan sonar and sediment sample collections in the Queen Charlotte region are not extensive but in the high priority area, the data set density is generally suitable for regional mapping of geohazards.

o Multibeam bathymetry is an effective technique for detailed mapping of potential geohazards however, it has not been utilized in Queen Charlotte region except for a few localized, site-specific studies.

o Offshore industry drilling practices have significantly improved over last 10 years.

o Extensive regulations for offshore hydrocarbon exploration and development exist worldwide and in Canada (for the East Coast and Beaufort Sea).

o It is recommended to carry out a regional desktop mapping study of potential marine geohazards. This study could focus on a high priority area for offshore oil exploration in the region and would make use of existing bathymetric, seismic, sidescan, sediment sampling and other available non-proprietary data. A proposed pilot study area is described in this report.

o It is recommended that further effort be expanded into locating, identifying and cataloguing existing marine data suitable for mapping geohazards. Additionally, in conjunction with Ministry offices, a comprehensive digital (GIS) data base should be created from historical (existing) marine mapping and environmental investigation products. Such a system would likely be based on an existing government in-house GIS system but it=s creation would be focused on applications for environmental and seafloor geohazard evaluation related to the offshore oil industry.

o Based on the presentation of results of the desktop study, it is recommended that a detailed bathymetric and marine high resolution geophysical data acquisition program be developed and undertaken in specific priority areas of importance to the British Columbia government. This strategic program would include multibeam bathymetry, sidescan sonar, high resolution seismic and sediment sample collection. The deliverables of such a pro-active program would fulfil a variety of needs and concerns that are highly pertinent to coastal community requirements, environmental and possible aboriginal issues that could arise as a direct consequence of offshore hydrocarbon exploration and development activity.

Acknowledgements

We would like to thank Vaughn Barrie, Ralph Currie and Kim Conway from the Pacific Geoscience Centre (PGC) for discussions of the various data bases available at PGC and Heiner Josenhans from the Atlantic Geoscience Centre (AGC) for providing information on the multibeam surveys in the Queen Charlotte area. We also thank Rosemarie Palmiere and Laura Richards from the National Energy Board for their help in locating some of the old industry (Shell and Chevron) data. Finally we thank Willi Rapatz for discussions on tides and currents.

Introduction

The British Columbia government is presently being asked by coastal community leaders to consider whether or not to lift the west coast moratorium on offshore petroleum exploration and development. As rumours start to spread there will be a resurgence of coastal and near shore environmental issues. In consideration of the issue, the British Columbia Government will require accurate and timely information on environmental and engineering hazards related to petroleum exploration and development in the coastal and near shore environment. This report discusses geohazard issues, i.e. hazards associated with geological processes, that need to be addressed before a decision can be reached allowing offshore petroleum exploration and development to proceed.

Lifting of the moratorium was considered in the mid 1980's. At that time a five-person federal-provincial panel was appointed to hold information meetings and public hearings throughout northern coastal British Columbia. The industry proponents at that time were Chevron Canada Limited and Petro Canada, although Petro Canada withdrew before the hearings were completed. Chevron and Petro Canada both submitted reports on environmental impacts of oil and gas exploration in the Queen Charlotte region (Chevron, 1982; Petro Canada, 1983). The panel also produced a report containing 92 recommendations covering many issues related to the environment (West Coast Offshore Environmental Assessment Panel, 1986). In their report the panel recommended the moratorium be lifted, subject to these recommendations. Both the provincial and federal governments agreed to negotiate a Pacific Accord that would allow the moratorium to be lifted. The backlash of public opinion from the Valdez oil spill that occurred at the same time influenced the two governments to continue the moratorium.

The information gathered during the panel hearings, and contained in the industry submissions and the subsequent recommendations by the panel provide a solid basis for environmental issues. None of the reports mentioned above adequately address geohazard issues. A few pages are devoted to these issues in the Chevron and Petro Canada reports, in Chevron's subsequent response to several of the panel's concerns (Chevron, 1985), and in the panel report.

The purpose of this report is to address potential marine geohazards in the Queen Charlotte region. It begins with a discussion of the hydrocarbon potential of the region in order to highlight areas where industry is expected to focus their attention, particularly during initial exploration phases. The report lists the geological hazards that may occur during hydrocarbon exploration and development and discusses their potential impact on the environment. A summary of the techniques available to map these hazards follows. It then discusses the socio-economic concerns that may arise as a consequence of these geohazards.

The report recommends a pilot study be carried out to map potential geohazards within a smaller region of the Queen Charlotte study area The purposes of this study are (1) to demonstrate methodologies available for mapping these hazards and (2) to provide a regional overview of potential hazards in one of the key areas within the Queen Charlotte region. The area was selected based on its hydrocarbon potential and the socio-economic impact expected. The location of the pilot study was also selected to ensure enough data are available to carry out regional scale mapping.

The report also provides an indication of where existing data for hazard mapping may be found. Finally a number of conclusions and recommendations are provided for future work and discussion.

1.0 Hydrocarbon Potential of the Queen Charlotte Basin

1.1 Geological setting

o Regional framework

Approximately 200 million years ago during the Mesozoic period (Table 1.1) a crustal block, composed of older Wrangellia, Alexander and Stikine blocks or terranes, collided with and accreted (joined) to what was then the western margin of North America. This crustal block now forms part of the western edge of North America. Present-day Vancouver and Queen Charlotte Islands and the region surrounding them are mostly underlain by Wrangellia terrane (Fig. 1.1).

The Insular Belt (Fig. 1.1), the westernmost tectonic belt making up the Canadian Cordillera, includes Wrangellia and Alexander terranes plus several other terranes

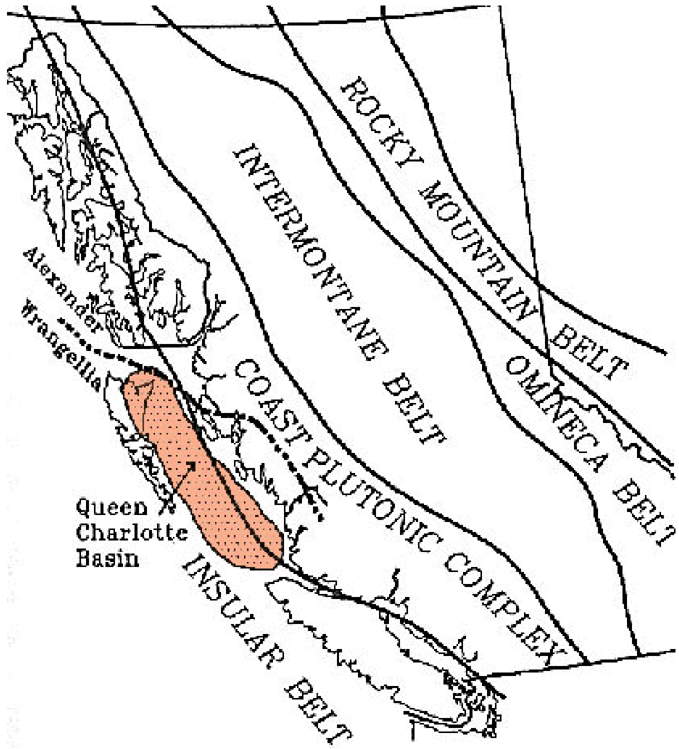

Figure 1.1: *Position of the Queen Charlotte Basin (in brown) with respect to the five major tectonic belts of the Canadian Cordillera and approximate boundary between rocks of Wrangellia and Alexander terrane affinities (after van der Hyden, 1989).*

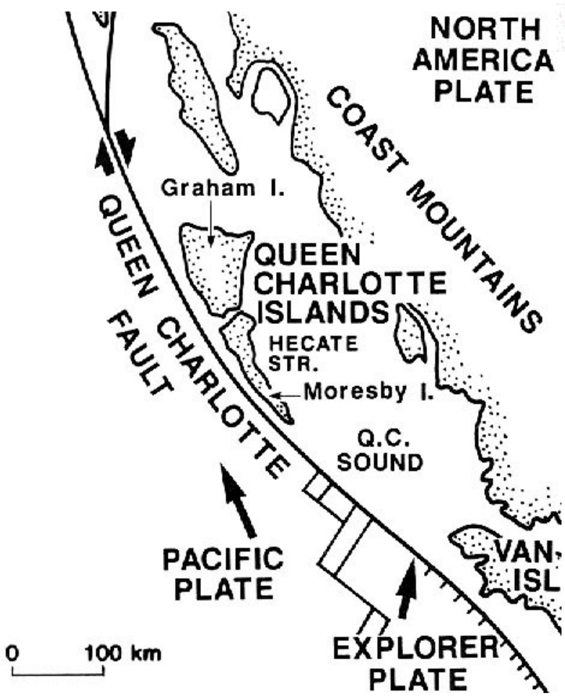

Figure 1.2: *Current plate tectonic setting in the Queen Charlotte area (from Hyndman and Hamilton, 1991).*

at the south end. The northern section of the Insular belt (North American plate) is separated from the Pacific (oceanic) plate by the Queen Charlotte Fault and the Explorer plate (Fig. 1.2). The Queen Charlotte Fault, which extends from Queen Charlotte Sound just north of the Explorer plate to offshore Alaska, is a comparatively young transform fault. The relative horizontal motion along this fault has the Pacific plate moving northward relative to the North American plate.

Although there are several basins on the west coast of British Columbia this report only discusses the Hecate and Queen Charlotte Basins and their

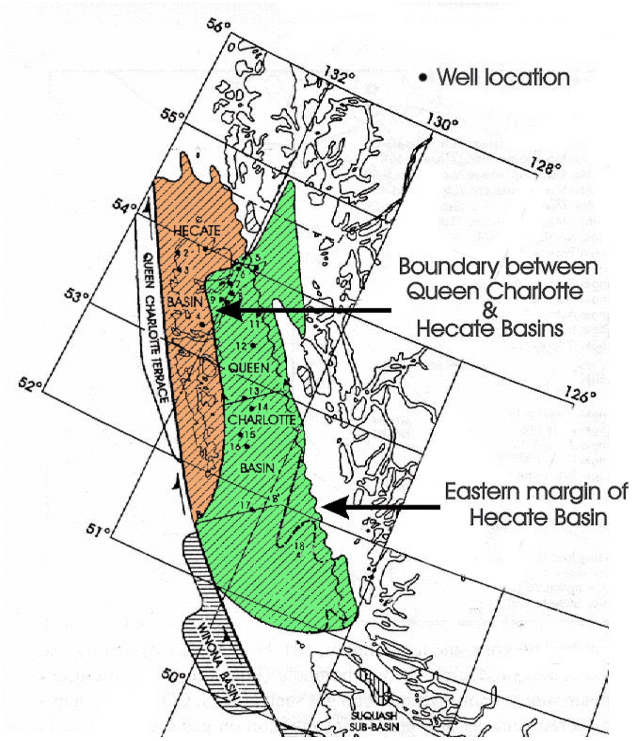

Figure 1.3: *Approximate outlines of the Queen Charlotte (green) and Hecate(brown) Basins (modified from Hannigan et al., 1998). The well numbers correspond to those in Tables 1.2 and 1.3.*

o Basement complex

Early geological interpretations of the Queen Charlotte region placed Wrangellia and Alexander terranes beneath Hecate and Queen Charlotte Basins. Recent studies indicate they are only underlain by Wrangellia terrane (Fig. 1.1) of early Jurassic and older volcanic and sedimentary rocks (Thompson et al., 1991).

The location of Wrangellia terrane with respect to the basins is important since this terrane contains potential hydrocarbon source rocks. Hydrocarbon source rocks are rocks containing enough organic matter (TOC equals total organic content) to generate oil and gas under correct temperature and pressure conditions These rocks have been investigated on land where they are exposed at the surface (Fig. 1.4) but have not been encountered in offshore wells. Several potential associated sub-basins in Dixon Entrance and near Banks Island (Fig. 1.3). Thompson et al. (1991) define the Hecate and Queen Charlotte Basins as consisting of all Middle Jurassic and younger rocks found on the Queen Charlotte Islands and offshore beneath Dixon Entrance, Hecate Strait and Queen Charlotte Sound (Table 1.1). The Hecate Basin is a Cretaceous basin that underlies most of the Queen Charlotte Basin and all of the Queen Charlotte Islands where it is exposed at the surface (Fig. 1.3). The Queen Charlotte Basin is an Upper Tertiary (Neogene) basin that covers the green region in Fig. 1.3. The boundaries for these basins are the Queen Charlotte Fault to the west, the eastern margin of Hecate Strait and Queen Charlotte Sound to the east, the northern margin of Dixon Entrance and the southern margin of Queen Charlotte Sound. These boundaries form the region investigated in this report.

GEOLOGICAL TIMESCALE AND MAIN FORMATIONS IN HECATE AND QUEEN CHARLOTTE BASINS

CENOZOIC	TERTIARY	Neogene	2	Skonun Formation
			23.7	Masset Formation
		Paleogene		Unnamed volcanics And sediments
MESOZOIC	CRETACEOUS	Upper	66.4	Unnamed sediments
				Unnamed volcanics
		Lower	77.5	Queen Charlotte Group
				Longarm Fm.
	JURASSIC	Upper	144	
		Middle	163	Moresby Group
				Yakoun Group
		Lower	187	Maude Group
	TRIASSIC	Upper	208	Kunga Group
			230	Karmutsen Fm.
		Middle	240	
		Lower	245	

Table1.1: *Approximate Mesozoic and Cenozoic time scale (millions of years before present) and geological formations and groups in the Hecate and Queen Charlotte Basins.*

hydrocarbon source rocks have been identified within Wrangellian basement. Upper Triassic Kunga Group limestones and thin-bedded argillites and Lower Jurassic Maude Group shales (Table 1.1) contain oil- and gas-prone organic matter. The quality of organic matter observed on Moresby Island is predominately associated with the level of organic maturation, i.e. the amount of heat (related to the product of time and temperature) the organic matter in the rocks have been exposed to. High heat flow associated with volcanism in the Middle and Upper Jurassic has resulted in generally poor hydrocarbon source potential for rocks on Moresby Island. Equivalent rocks on Graham Island are generally immature to mature[1] and have fair to good hydrocarbon source potential.

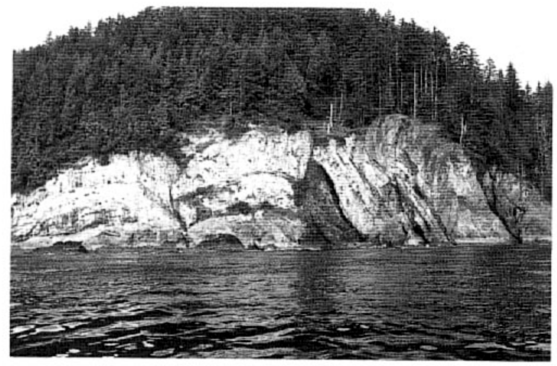

Figure 1.4: *Massive block of Middle Triassic Karmutsen basalt (black) faulted into core of anticline structure outlined by Upper Triassic Kunga limestone (after Lewis and Ross, 1991) The limestone is a potential oil source rock for the Queen Charlotte and Hecate Basins.*

The subsurface distribution of Kunga-Maude rocks is largely unknown but is expected to be highly irregular because there were several episodes of erosion from Middle Jurassic to Tertiary time. In particular, Cretaceous uplift and erosion was probably widespread in areas close to or landward (east) of the Hecate Basin margin (Fig.1.3) Kunga-Maude formations are therefore expected to be found in greatest abundance in the southwestern half of the region, beneath Graham Island and western parts of Dixon Entrance, Hecate Strait and Queen Charlotte Sound (Thompson et al., 1991).

o Cretaceous sediments

Several Mesozoic sedimentary rock units (Upper Jurassic and Cretaceous in age) have reservoir potential[2] (Table 1.1).

The base of the Upper Jurassic Longarm Formation, where it is exposed on southeastern Moresby Island, contains a thick package (up to 180 m thick) of boulder, pebble and granular conglomerate as well as coarse-grained sandstone. It grades upward into sandstone and shale with a total thickness of perhaps 450 m.

The overlying Cretaceous Haida Formation of the Queen Charlotte Group (Table 1.1) consists of a lower (basal) sandstone unit and an upper shale unit. The basal unit is a medium- to fine-grained sandstone with a conglomerate at the base a few tens of metres thick. The total thickness of the sandstone section has been estimated to be about 400 m. A shale unit with a thickness between 100

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1 Maturity is related to the cumulative amount of heat, i.e. burial history, that source rocks are subjected to during basin development. Immature implies the rocks have not been exposed to heat long enough while overmature implies the rocks have been exposed to heat too long.

2 Reservoir rocks are rocks that have sufficient porosity (void or pore space) to store useful quantities of oil and/or gas and permeability (the ability of a rock to transmit fluids) to produce oil and gas at a sufficient rate to be economical

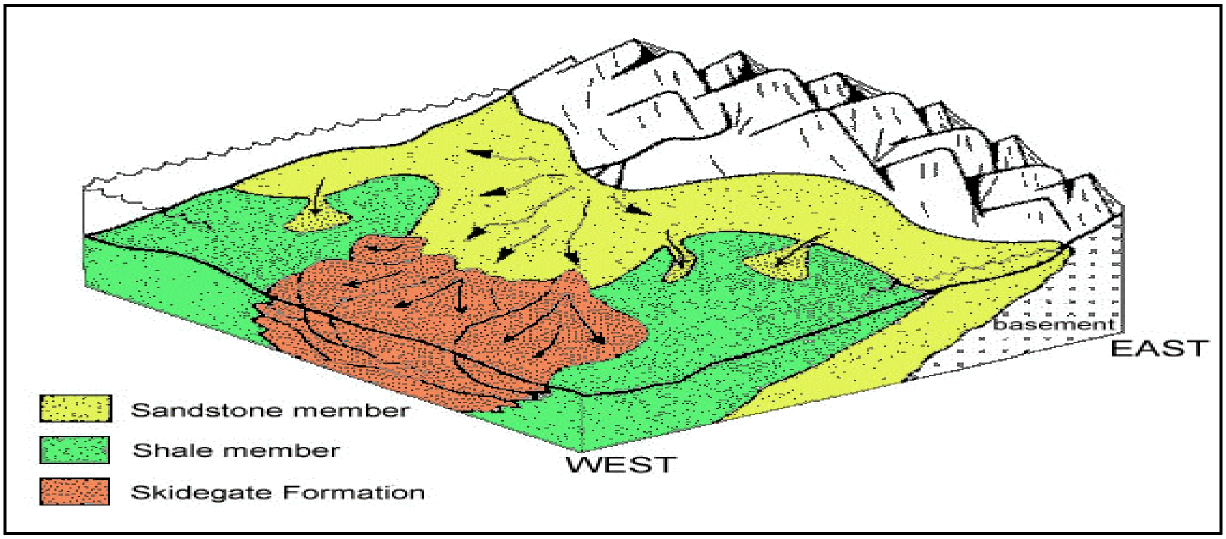

Figure 1.5: *Environmental relationship of the sandstone and shale members of the Haida Formation and the overlying Skidegate Formation at the time of deposition. The sandstone member reflects near-shore deposition strongly influenced by storm events. The shale member is a more offshore, deeper-water equivalent of the sandstone member. The Skidegate Formation consists of deep water sediments associated with sediment distributary systems (after Haggart, 1991).*

and 300 m overlies the sandstone member of the Haida Formation. It is a monotonous black, silty shale with thinly bedded siltstone and fine-grained sandstone at the top. The siltstone and sandstone beds are transitional to the overlying Skidegate Formation.

The Skidegate Formation consists of silty shale and interbedded turbidite sandstone (fine- to coarse-grained). The fine- to coarse- grained sandstone beds often cut channels into the underlying Haida Formation. Figure 1.5 is a schematic diagram depicting the environmental relationship between the Haida sandstones and shales and the overlying Skidegate Formation at the time of deposition.

The Honna Formation lies above the Skidegate Formation and consists predominantly of cobble conglomerate and medium- to coarse-grained sandstone, with minor fine-grained sandstone and shale occurring locally. The base of the formation is generally characterized by thickly-bedded, coarse conglomerates that thin and fine upwards into sandstone. At the top of the Formation turbidite sandstone is interbedded with shale. Unnamed Cretaceous volcanics and shales extend from the top of the Honna Formation to the base of the Tertiary.

Portions of the conglomerate and sandstone units within the Longarm and Haida Formations have reservoir potential. The best reservoir potential occurs in the basal sandstone unit of the Haida Formation deposited along ancient shorelines aligned northwest-southeast in the Queen Charlotte Islands area and probably the western parts of Dixon Entrance, Hecate Strait and Queen Charlotte Sound (Hannigan et al., 1998; Lyatsky and Haggart, 1993). The shale members within the Longarm, Haida, Honna and Upper Cretaceous Formations provide potential seals to hydrocarbon flow as these rocks have very low permeability. The volcanic beds above the Honna Formation also provide seals.

Source rock potential within the Cretaceous is limited to a few carbonaceous sandstone, conglomerate and shale units within the Haida, Skidegate and Honna Formations. The TOC is generally low for these rocks with only limited scope for oil generation and a low but possible chance for gas generation.

o Tertiary sediments

Paleogene sediments consisting of sandstone, conglomerate and shale occur beneath volcanic rocks of the Neogene Masset Formation. The reservoir quality of these sediments appears to be poor where they have been observed in wells and outcrop (for example on Hippa Island). Assessment of reservoir potential of Paleogene sediments will therefore remain problematical until more information is available.

The Neogene Skonun Formation contains large volumes of mixed marine and non-marine sandstone, and conglomerate. It spans the entire Neogene, from the base of the Miocene to the top of the Pliocene. The widespread geographical distribution, large volume and relatively good reservoir characteristics of Skonun sandstones and conglomerates make them the principle petroleum targets in the Queen Charlotte Basin (Hannigan et al., 1998). Interbedded shales within the Skonun Formation provide potential seals to hydrocarbon flow. Tertiary coal and carbonaceous beds, which are gas prone, are potential source rocks. Coal beds are abundant in the northern half of the Queen Charlotte Basin where non marine deposits are thick and widespread. Skonun shales and siltstones locally contain organic matter with good oil and gas source potential. Tertiary Formations have lower source rock quality than Kunga-Maude rocks, but they occur in greater volume and are distributed over a wider region.

1.2 Previous exploration activity

o Industry activity

The first petroleum exploration well was drilled on the west coast of Graham Island in 1913 by the B.C. Coal Company (see Fig. 1.3 and Tables 1.2 to1.3 for well locations and descriptions). A number of oil seeps and occurrences on land have been documented by Hamilton and Cameron (1989). These seeps, along with the knowledge that sedimentary rocks existed on the surface and within the subsurface, encouraged further exploration activity. An additional 8 wells (6 by Richfield, 1 by Royalite and 1 by Union Oil) were drilled on Graham Island between 1949 and 1971. Richfield also carried out land and marine (in Hecate Strait) seismic surveys in 1960 before drilling the last of the 6 wells. The last well drilled on land was Bow Valley et al. Naden Harbour in 1984. Although some oil staining and shows were encountered in these wells no commercial hydrocarbons were discovered.

Well number in Fig. 1.3	Well name and location	Company	Total depth[1] (m)
1	Naden Harbour b-A27-J	Bow Valley et al.	-
2	Tian Bay	BC Coal Co.	-
3	Port Louis o-28-L	Union Oil	1570.0
4	Queen Charlotte No. 1	Royalite	-
5	Homestead Tow Hill d-93-C/103-J-14	Richfield	1804.5
6	Homestead Masset c-10-I/103-F-16	Richfield	552.0
7	Homestead Nadu River b-69-A/103-F-16	Richfield	1

Table 1.2: *Wells drilled on Graham Island (between 1913 and 1984).*

Well number in Fig. 1.3	Well name	Location	Total depth (m)
11	South Coho I-74	(53°33'32.60" N 131°25'48.90" W)	2780.1
12	Tyee N-39	(53°18'54.52" N 131°20'21.42" W)	3459.5
13	Sockeye B-10	(52°49'08.53" N 131°00'44.19" W)	4771.9
14	Sockeye E-66	(52°45'24.62" N 130°55'19.44" W)	2786.5
15	Murrelet L-15	(52°24'41.30" N 130°47'38.00" W)	2919.4
16	Auklet G-41	(52°20'16.12" N 130°36'32.77" W)	2370.4
17	Harlequin D-86	(51°55'03.58" N 129°58'12.35" W)	3240.9
18	Osprey D-36	(51°35'06.20" N 129°20'47.65" W)	2530.4

Table 1.3: *Wells drilled offshore by Shell Canada (between April, 1968 and April, 1969).*

Shell Canada Limited carried out geological mapping programs on the Queen Charlotte Islands starting in1963 and conducted marine reflection seismic surveys between 1965 and 1967. Shell drilled 8 offshore wells between 1968 and 1969, two in Queen Charlotte Sound (Harlequin and Osprey) and the remaining 6 in Hecate Strait (Table 1.3). Previous to this drilling nothing was known of the offshore Queen Charlotte Basin. The seismic and drilling program carried out by Shell provide a partial understanding of the nature of the Tertiary Queen Charlotte Basin and its hydrocarbon potential (Shouldice, 1971). Although no significant accumulations of hydrocarbons were encountered several small hydrocarbon shows were observed in 3 wells (Sockeye B-10, South Coho I-74 and Murrellet L-15) along with the appearance of gas (mostly methane and ethane) in drilling mud in Tyee –39, Sockeye B-10 ands Harlequin D-86. After the 8 wells were drilled Shell farmed out their leases to

Chevron Canada Limited. Chevron collected additional seismic data in 1971 but in 1972 the federal government imposed an indefinite moratorium on offshore petroleum exploration along the west coast in response to environmental concerns. No further exploration activity has occurred in the offshore since then.

o Government activity

In the late 1980's the Geological Survey of Canada, through the Frontier Geoscience Program, carried out detailed geological, geophysical and geochemical studies of the Queen Charlotte region in order to understand the evolution of the Queen Charlotte and Hecate Basins and their hydrocarbon potential . A Geological Survey of Canada paper edited by Woodsworth (1991) provides a comprehensive review of this study. Data from offshore marine seismic surveys (reflection and refraction) were collected, analysed and interpreted to supplement the data collected by Shell and Chevron. One thousand kilometres of deep marine reflection seismic data were collected in 1988 (Fig. 1.6). The data illustrate that Tertiary sediments have a variable thickness (Fig. 1.7) and that the sediments, as well as the underlying Mesozoic basement rocks, are extensively faulted (Fig. 1.8) and form complex patterns of sub-basins (Rohr and Dietrich; 1990, 1991). Heat flow and geochemical studies were also carried out to investigate source rock potential of the region.

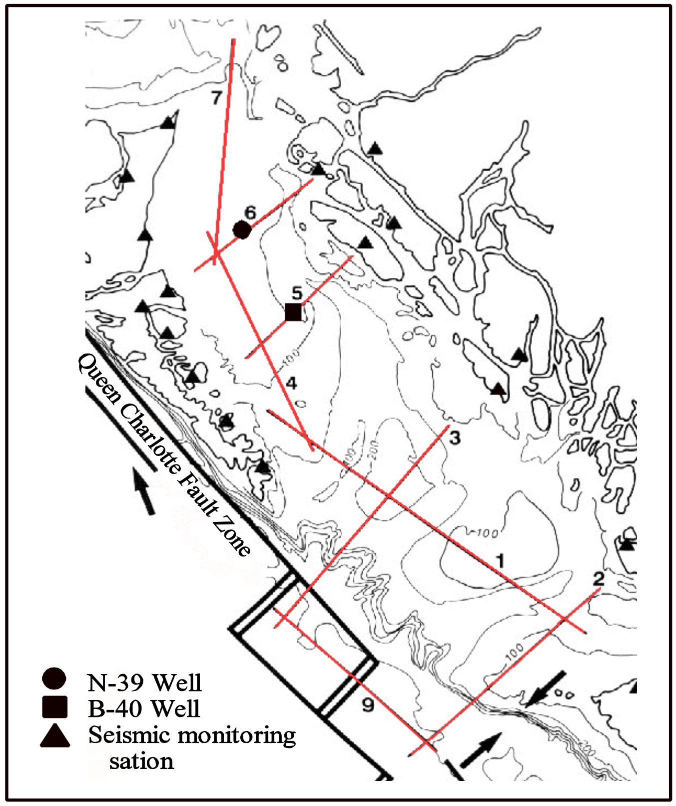

Figure 1.6: *Location of GSC reflection seismic lines (from Rohr and Dietrich, 1991).*

1.3 Hydrocarbon potential

o Basin characteristics

A sedimentary basin may or may not contain economic volumes of oil and gas. Hydrocarbons will only accumulate in a basin if several factors or conditions are fulfilled. These factors are discussed in relation to the Hecate and Queen Charlotte Basins in this section.

Presence of source rocks

Potential Mesozoic and Tertiary source rocks have been observed within the Queen Charlotte region. The distribution of the quality, total organic content (TOC), and maturation level of the source rocks is only partially resolved though. There is concern that volcanic activity in the region produced high heat flows leading to overmature source rocks in some areas. On the other hand oil and gas shows, as onshore seeps and in offshore wells, clearly indicate the presence of hydrocarbons within the basins. The requirement that potential source rocks occur within the basins is therefore satisfied, subject to the above caveats.

Presence of reservoir rocks

Potential reservoir rocks have been noted within Upper Jurassic, Cretaceous and Neogene sandstones and conglomerates. The basal sandstone within the Cretaceous Haida Formation and the Neogene Skonun Formation are two of the more prospective reservoir intervals within the Queen Charlotte and Hecate Basins. The timing of oil and gas migration from source rocks into potential reservoirs is not completely determined, although there are strong indications that hydrocarbons could have migrated into reservoir rocks (for example the Sockeye B-10 well).

Presence of seals

There are abundant shales and volcanic rocks within the basins to provide seals or barriers to hydrocarbon flow. When these rocks are juxtaposed adjacent to a reservoir they prevent oil and gas from escaping.

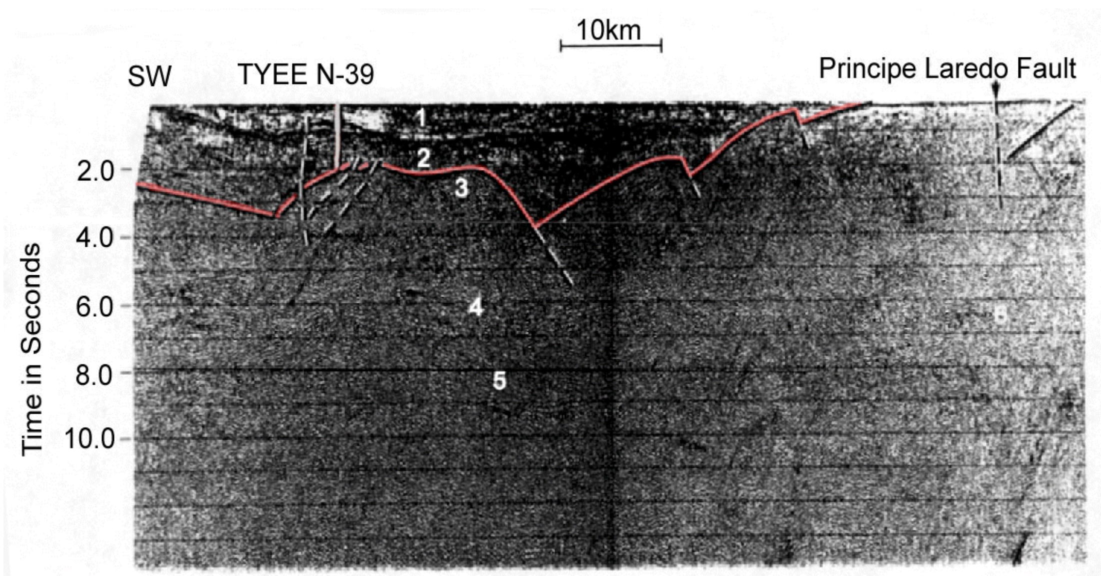

Figure 1.7: *Deep reflection seismic section (Line 6 in Fig. 1.6) showing basin outline within the top 4 seconds (red line) and basement faulting (from Rohr and Dietrich, 1991).*

Presence of traps

A hydrocarbon trap is formed when reservoir rocks are arranged in such a way that hydrocarbons are prevented from leaking out. A trap can either be structural or stratigraphic. Structural traps provide a seal by structurally controlling reservoir boundaries. Potential structural traps, such as the folds and faults illustrated in Fig.1.8, have been observed within the Mesozoic (Cretaceous) and Tertiary sections of the Hecate and Queen Charlotte Basins respectively. Stratigraphic traps provide seals by stratigraphically controlling reservoir boundaries. For example a stratigraphic trap could be caused by lateral changes in formation going form a reservoir sandstone to a shale seal (facies change). In this case the shale prevents hydrocarbons to flow out of the reservoir. Traps can also be a combination of structural and stratigraphic. An anticline, a convex upward bulge, is structural for example. However, a sandstone formation in the anticlinal structure would only form a reservoir if a seal (shale) lies above it. Hydrocarbons can migrate into the sandstone anticline but will not remain there unless a seal exists above the reservoir.

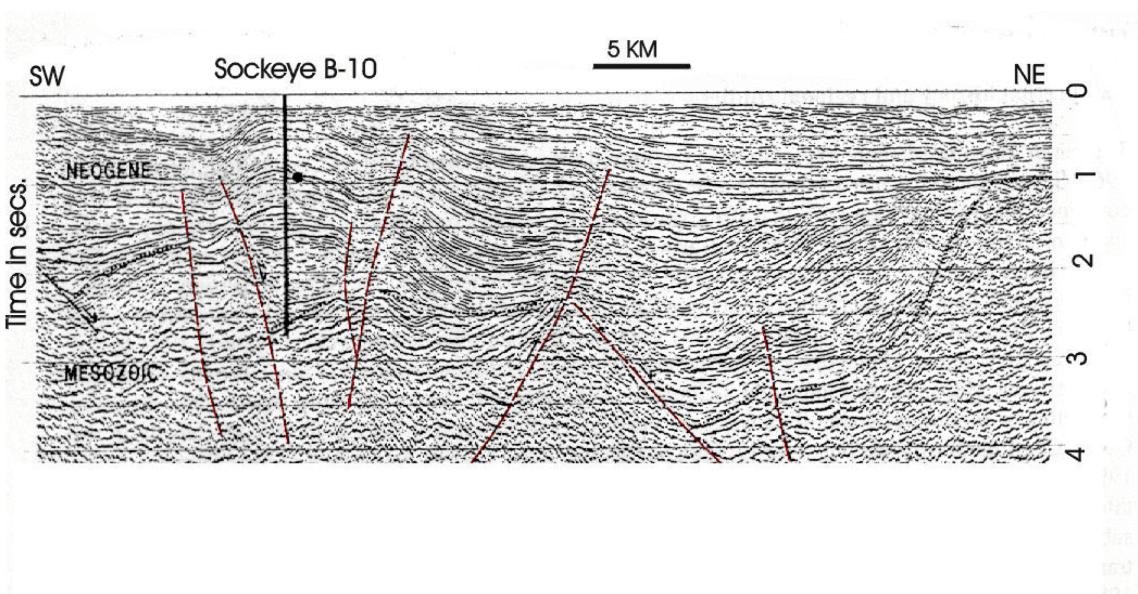

Figure 1.8: *Reflection seismic profile (Line 5 in Fig. 1.6) from Rohr and Dietrich (1990) showing structural features and faulting (red lines) within the Mesozoic and Tertiary. The solid circle indicates the position of the oil show at the Sockeye B-10 well.*

The basic factors (source rocks, reservoir rocks, seals and traps) required for the generation, migration and accumulation of oil and gas have been shown to exist in the Hecate and Queen Charlotte Basins. The Geological Survey of Canada carried out a resource assessment of the region in 1998 using this information (Hannigan et al., 1998). They assessed the reserves using three separate plays (classes of reservoirs) based on reservoir age and type of traps expected.

o Cretaceous oil and gas play

This oil and gas play involves all structural and stratigraphic traps within the Cretaceous Hecate Basin beneath and adjacent to the Tertiary Queen Charlotte Basin (Fig. 1.9). Potential hydrocarbon traps involve Cretaceous sandstones, principally within the basal units of the Haida Formation, in fault block or anticlinal structures. The most prospective area occurs in a southeast-trending zone from central Graham Island to southwestern Queen Charlotte Sound.

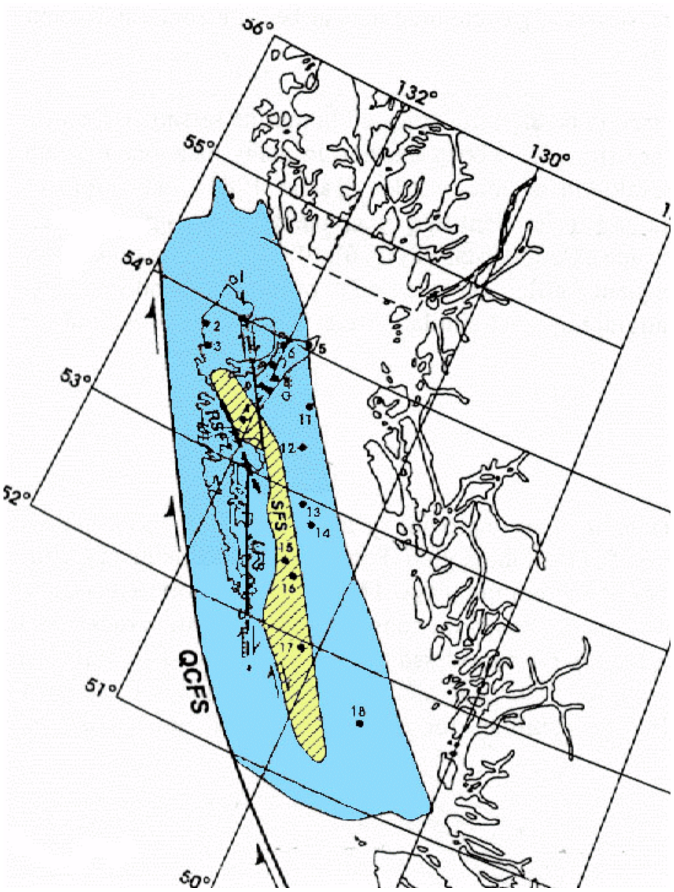

Figure 1.9: *Cretaceous oil and gas play is outlined by the two colours. The area in yellow is the more prospective region with moderate to high potential (basal sandstone of the Haida Formation).*

o Miocene oil and gas play

Two play types, differentiated on trap type and timing of trap formation, were used to assess the Neogene section within the Queen Charlotte Basin. The Miocene (lower Neogene) oil and gas play occurs basin wide in an area of about 40,000 km^2 and involves structural (tilted fault blocks, fault-related rollover and drag features, and drape anticlines) and stratigraphic (unconformities and

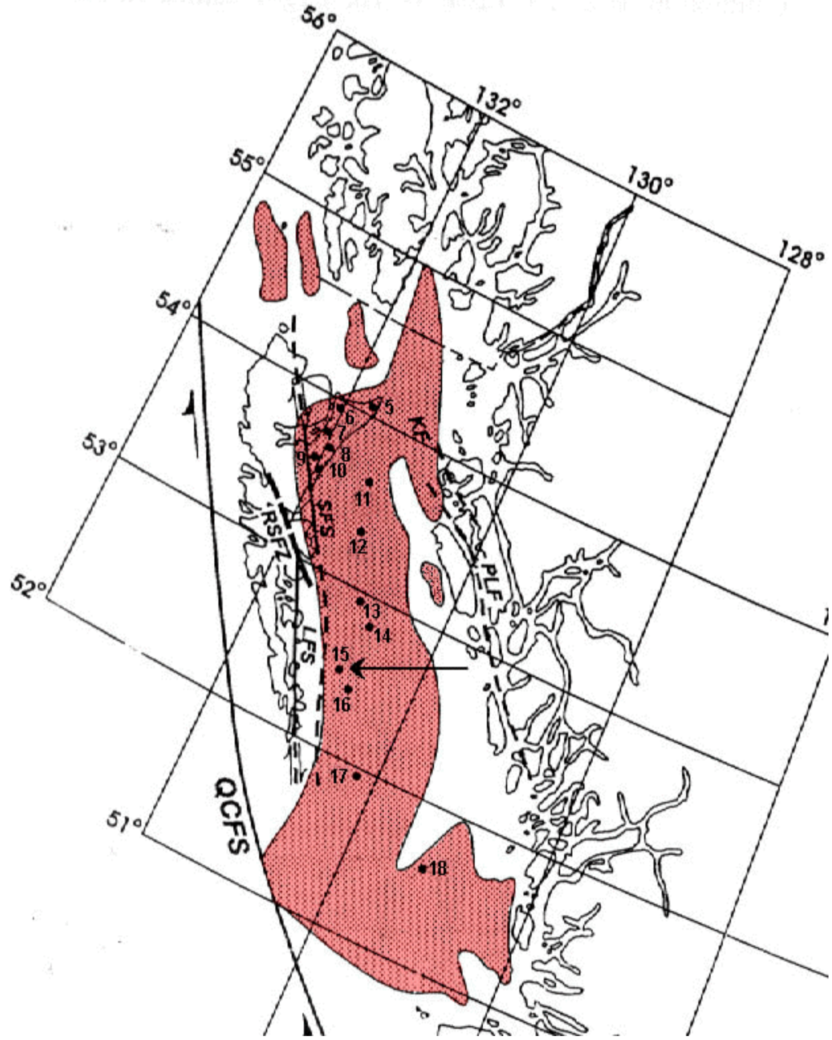

Figure 1.10: *Region of Miocene oil and gas play is outlined in colour. The Pliocene play covers the northern portion of this area north of the Murellet L-15well (see arrow).*

pinchouts) traps that developed within the Skonun Formation during the Miocene (Fig. 1.10).

o Pliocene oil and gas play

The Pliocene (Upper Neogene) oil and gas play overlaps the northern portion of the Miocene play north of the Murellet well (Fig. 1.10). Pliocene structures include large-amplitude folds and faulted anticlines (flower structures) developed in the Skonun Formation during the Pliocene.

OIL POTENTIAL

Play name	Expected no. of producing fields (mean)	Median play potential(in place million m^{3*})	Median of largest field size in place million m^3)
Cretaceous oil	62	392	96
Miocene oil	28	574	165
Pliocene oil	13	398	233
Total oil	**103**	**1,560 (or 9.9 billion bbls)**	n/a

GAS POTENTIAL

Play name	Expected no. of producing fields (mean)	Median play potential (in place million m^{3*})	Median of largest field size in place million m^3)
Cretaceous gas	50	75,435	20,675
Miocene gas	40	285,710	71,190
Pliocene gas	30	321,750	95,774
Total gas	**120**	**733,760 (or 26 trillion ft^3)**	n/a

Table 1.4: *Oil and gas potential in Hecate and Queen Charlotte Basins (modified from Hannigan et al., 1998).* * *1 m^3 is approximately equal to 6.28 barrels and 35.3 ft^3*

Table 1.4 summarises the assessment of Hannigan et al. (1998). The table lists the number of oil and gas reservoirs (fields) expected for each of the three plays as well as the median oil and gas play potential and the median of the largest expected oil and gas field. The total number of fields and total expected oil and gas volumes are also given. These numbers are based on limited information since there are no existing oil or gas reservoirs in the area to provide guidance. There is only limited seismic data and well control in the offshore as well so structural and geological mapping is sketchy at best. On the other hand these estimates are more than encouraging and are of comparable size to those in the Jeanne d'Arc Basin, offshore Newfoundland, where the Hibernia and Terra Nova fields are located. For more details of the geology, play definitions and estimation procedures see the report by Hannigan et al., 1998 and the references provided in this report and other reports referenced here.

1.4 Canadian offshore oil and gas regulations

The principal legislation governing offshore oil and gas activities is the Canadian Oil and Gas Production and Conservation Act passed in 1969 and amended in 1970, 1971 and 1972 and by the Canada Oil and Gas Act (COGA). Section 12 of the Act gives the Governor in Council authority to make regulations respecting the exploration and drilling for and the production, conservation, processing and transportation of oil and gas.

The Canada Oil and Gas Drilling Regulations were announced in January,1979 and were amended in 1980. The regulations were designed to meet three basic objectives: to ensure a safe work place; to protect the environment from pollution; and to ensure that oil and gas resources are not wasted.

The Minister of Natural Resources Canada was responsible for the above Acts. Initially the administration of the legislation and the day-to-day supervision, control and enforcement of the Act was the responsibility of the Resource Management Branch of the Canada Oil and Gas Lands Administration (COGLA). This branch was headed by a Director-General who was also the Chief Conservation Officer as defined in the Act. COGLA was responsible for offshore as well as onshore federal lands.

Over the last two decades responsibility for the administration of a significant portion of the east coast offshore has been delegated to Offshore Boards in Newfoundland (Canada-Newfoundland Offshore Petroleum Board) and Nova Scotia (Canada-Nova Scotia Offshore Petroleum Board). These Boards are operated jointly by the federal government and the corresponding Province. The legislation governing these Boards is contained within the Canada-Newfoundland Atlantic Implementation Act and the Canada-Newfoundland Atlantic Accord Implementation (Newfoundland) Act with similar Acts in Nova Scotia. In these cases the Minister of Natural Resources Canada as well as the corresponding Provincial Ministers are jointly responsible for the Act . Many sections of these Acts are identical to the Canadian Oil and Gas Production and Conservation Act.

With the formation of the two offshore Boards, the responsibility for administering the frontier oil and gas areas of Canada was reorganized. Regulations for the east coast offshore are looked after by the two Boards while the National Energy Board (NEB) and the Department of Indian and Northern Affairs (DIAND) share the responsibility for onshore regulations. All other offshore regions, including the west coast, are the responsibility of NEB.

For offshore oil and gas operations the operator is required to submit a comprehensive plan of the proposed drilling program which must contain the information specified in the Acts. The regulatory authority then carries out a thorough assessment of the information and plan to ensure that the equipment, procedures and other elements of the plan meet all the requirements of the regulations, including investigation of potential geohazards in the exploration area.

After a proposed drilling program is approved the operator must then apply for and obtain a separate authorization to drill each well in the program. The operator is required to submit an application to the regulatory authority at least 45 days prior to spud date. Various other departments (for example Department of Fisheries, Ministry of Transport, etc.) must also be informed by the operator. During the drilling stage the operator must supply daily progress reports and projections of work for the next day. Any unusual circumstances (such as gas kicks) must be reported immediately.

The regulations cover all aspects of offshore drilling and for that matter seismic acquisition. Below is a sampling of some environmental issues covered by the regulations:

- the disposal of drill cuttings, drill fluids and produced natural gas

- methods of collecting waste engine oils from oil sumps

- the storing and handling of drilling fluid additives, fuel and other oils

- the handling and disposal of any waste materials (in a way that does not damage the environment)

- the storage and/or burning of produced oil, gas and water from production tests

- training of staff in safety and environmental issues

- procedures for handling blowouts and gas kicks

- site investigation procedures

Oil and gas exploration has been carried out in the offshore areas of Canada since the 1960's. Hundreds of thousands of kilometres of seismic data have been collected on the Scotian Shelf, the Grand Banks, offshore Labrador, in the Gulf of St. Lawrence, off the British Columbia Coast and in Beaufort Sea with no significant problems. Over 300 wells have been drilled in the offshore and condensate has been produced (Cohasset-Panuke field) offshore Nova Scotia without any major environmental problems. The Canadian Petroleum industry has a very good record in offshore exploration and production practices. In addition, legislation and regulations have been put in place to protect the environment and to ensure that offshore oil and gas operations are carried out safely.

2.0 Environmental and engineering geohazards

2.1 Offshore petroleum industry exploration and production practices

o Seismic acquisition

Seismic acquisition constitutes the first step in any offshore exploration program and may occur from time to time during and after exploration. The level of seismic activity will vary from year to year but tends to occur less frequently and be more localized during later stages of an exploration program. Reflection seismic data is collected from ships specially designed for this purpose. Present industry practice is to use air guns as the energy source, thus replacing the earlier practice of using dynamite. Air guns are simply a towed-array of steel cylinders of different volume, each capable of containing compressed air to pressures of two thousand pounds per square inch (psi), towed relatively close behind the seismic survey vessel at a maximum depth of 20 m. The air in these cylinders is simultaneously released into the water once every 5 to 10 seconds, depending on the anticipated depth of exploration. Studies by the Department of Fisheries and Oceans (Wright, 1982) assessed available data and concluded that air guns do not pose a hazard to fish. There have been numerous seismic surveys using air guns as sources carried out on the west coast offshore by the University of British Columbia and the Geological Survey of Canada as well as the surveys carried out by Shell Canada and Chevron Resources during earlier exploration programs.

In addition to the energy source, an array of hydrophones (pressure detectors) is towed behind the survey vessel. The hydrophones are towed on cables that can be up to 3000 m or more in length, with several towed side by side during three dimensional (3D) seismic acquisition. During the initial stages of exploration two dimensional (2D) seismic data is usually acquired using a single towed cable. The data is acquired on a grid of lines with a spacing determined by the particular exploration objectives. Three dimensional surveys are usually carried out during the delineation drilling and production stages of a project.

A study by Woods Hole Oceanographic Institute (1976) noted that the present methods of seismic acquisition appear to have no adverse affects on the environment. The report also noted that surveying is not so intensive that it interferes with other operations. There have been occasions though when fishermen have complained that the survey vessels and towed cable arrays have interfered with fishing operations.

o Drilling operations

Once the seismic data have been processed and interpreted, the next stage is to conduct an exploratory drilling program. After tentative locations have been selected, a “site survey” of each locality and the region surrounding it must be conducted to determine the characteristics of the sea floor and the shallow subsurface geology. This consists of detailed bathymetric, sidescan sonar, high resolution sub-bottom acoustic profiler surveys and some sediment sampling or in-situ testing to provide information on the seabed and the upper 15 to 30 m of the sub surface (see section 2.3 for further details). These data are used to determine seafloor topography, channels, ridges and potential areas for slumping and slope failure. The data provide information on active areas of sediment transport on the seafloor and identify shallow gas pockets and near surface faults. Additionally, a multi-channel, high resolution, seismic survey is often used to identify likely zones of high pressure gas in the top 700 to 1000 m of the subsurface (Fig. 2.12). Potential hazards and safety issues flagged during the site survey must be addressed before drilling can commence. Such surveys are required for offshore drilling world wide and imposed by insurers to establish potential risk for each operational area. Table 2.1 list some of these hazards and the methods that can be used to map these features. Further details can be found in Sections 2.2 and 2.3.

The choice of drilling rig for the offshore depends on water depth, depth to exploration target(s), climatic conditions and ocean conditions as well as stability, design criteria for survival, operating costs and availability. Possible choices are drillships, jack-up rigs, platforms and semi-submersible (anchored or dynamically positioned). The water depths in the Queen Charlotte and Hecate Basins of interest to industry are too deep to allow the use of jack-up rigs and platforms. The most likely drilling unit will be a semi-submersible rig. Semi-submersibles are more stable than drillships and can withstand more severe weather conditions. Fig 2.1 is a schematic that issustrates a semi-submersible drilling rig.

The drilling procedures used are standard for offshore practices in use throughout the world. These procedures have been used in all previous offshore drilling programs in Canada.

The first step is to drill a large (110 cm) hole and insert 100 cm steel casing to a depth of 30 to 60 m below the seafloor. This casing is then cemented into place. It is used to hold the wellhead and smaller diameter casings.

Below this an additional 65 cm hole is drilled and a 65 cm (approximate) diameter casing is installed and cemented in place. Government regulations requires the minimum depth must be at least 250 m but often the depth is increased to ensure safety. This passes the load of the wellhead and smaller diameter casings to more highly consolidated sediments at depth. A blowout preventer (BOP) is then lowered to the seafloor on a marine riser and connected to the wellhead (Fig. 2.1). The BOP restrains blowouts by controlling the influx of formation fluids. Once the BOP and marine riser are in place, drilling fluids can be returned to the surface for analysis and recycling.

Drilling fluids are required to counterbalance the pressure of fluids within the formations being drilled. These drilling fluids also remove the cuttings from the hole. Before the BOP and marine riser are in place drilling (to a depth of approximately 250 m) is carried out using sea water with intermittent amounts of high viscosity mud (guar gum). The spent drilling fluid is returned to the sea floor. Below this depth, drilling mud is a mixture of bentonite (gel) and fresh water which is returned to the surface and then re-circulated into the well. The surface tanks and mud traps must

OBJECTIVE / PROBLEM

PROBLEM		TYPE OF DRILLING RIG: JACK UP					DRILL SHIP/SEMI-SUB						PLATFORM			
		Rig Selection	Rig Location	Wellhead Relocation	Leg Penetration	Casing Program	Rig Selection	Rig Location	Wellhead Relocation	Wellhead Stability	Anchors	Casing Program	Design	Location	Pile Depth	Casing Programme
Shallow	0-75m		+		+	+		+		+	+	+		+	+	+
Faults	75-500m		+			+		+		+		+				+
Gas	0-75m		+		+	+		+		+	+	+		+	+	+
Pockets	75-500m		+			+		+		+		+				+
Sedimentary Succession		+	+		+	+		+		+	+	+	+	+	+	+
Buried Valleys			+		+	+		+		+	+	+		+	+	+
Water Depth		+	+		+	+	+			+	+	+	+		+	+
Sea-bed Conditions		+	+		+		+			+	+	+	+	+		
Man Made Obstructions			+					+			+			+		
Recovery of lost Equipment				+					+		+					
Meteorological Conditions		+	+				+	+					+			
Sea Surface Conditions		+	+				+	+					+			
Sub-surface Currents		+	+				+	+		+			+			
Water Density			+					+					+			

TOOL / PROBLEM

PROBLEM		TYPE OF SURVEY TOOL: GEOPHYSICAL							ENVIRONMENTAL				
		Echo Sounder or Swath System	Sidescan Sonar	Pringer Profier	High Resolution Boomer Profiler	Multi-electrode Sparker or Airgun	Multi-channel, Digital Seismic System	Magnetometer	Waverider Mooring	Meteorological Station	Tide Gauge	Current Meter	CTD Meter
Shallow	0-75m				X	X							
Faults	75-500m					X	X						
Gas	0-75m				X	X	X						
Pockets	75-500m					X	X						
Sedimentary Succession				X	X	X	X						
Buried Valleys				X	X	X	X	X					
Water Depth		X	X	X	X	X					X		
Sea-bed Conditions		X	X	X	X	X						X	
Man Made Obstructions		X	X	X				X					
Recovery of lost Equipment		X	X	X				X					
Meteorological Conditions										X			
Sea Surface Conditions									X				
Sub-surface Currents												X	X
Water Density													X

Table 2.1: A typical selection of seafloor geologic and environmental problems or objectives which can be encountered during an offshore exploration drilling or platform siting study and the types of survey systems or tools which are used for their identification and characterization.

be cleaned periodically by dumping the material into the sea to prevent loss of circulation and excessive wear on mud pumps. This is caused by the increase in finer size material in the drilling mud caused by re-circulation procedures.

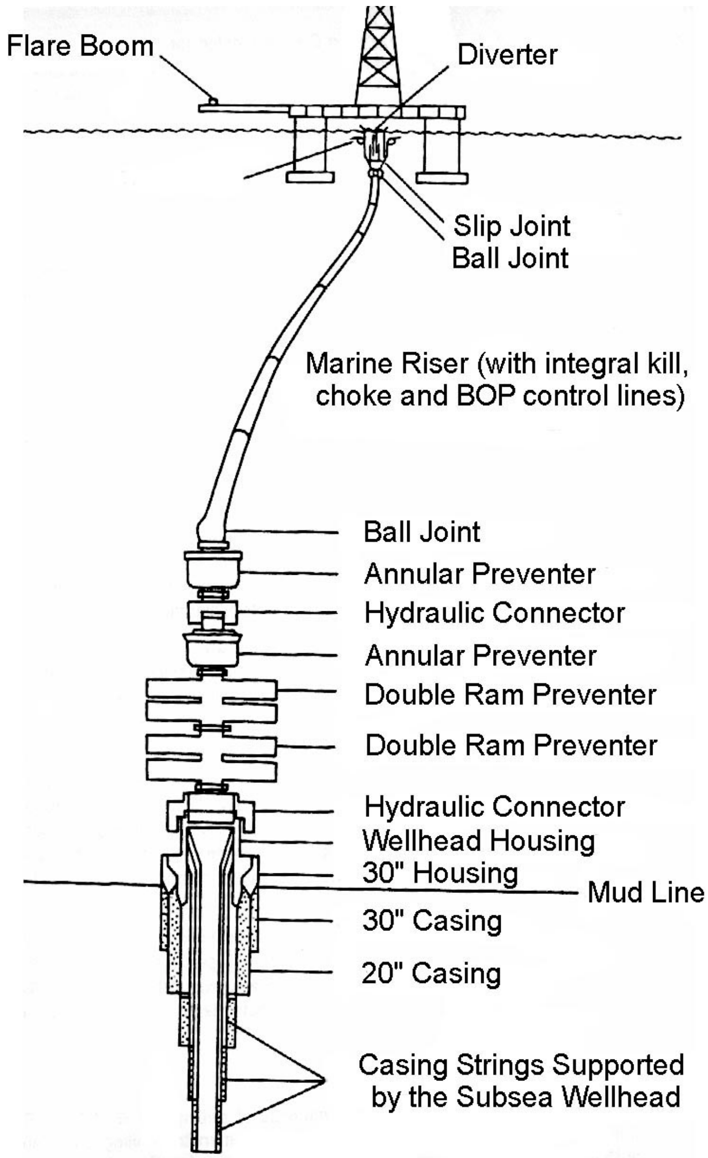

Figure 2.1: *Schematic of semi-submersible rig and sea floor blow out preventer (BOP) for offshore drilling operations (from Chevron Canada, 1982).*

A 50 cm hole is then drilled to a depth of approximately 1000 m and a 35 cm casing installed and cemented in place. A 30 cm hole is then drilled to a depth of approximately 2500 m, the depth depending on conditions and requirements. After the hole is logged, i.e. specialized measurements using downhole tools, a 25 cm intermediate casing is cemented into place. A 23 cm hole is then drilled and logged. This has been the most common diameter hole used to reach exploration depth for most offshore wells drilled in Canada. Coring and logging are conducted before deciding to install the last casing and test the well. If a deeper hole is required smaller diameter holes and casing are used. If a well is tested for flow rate and production capacity, the fluids are burned off on the surface from a flare boom mounted in the drill platform.

Once an exploration well is evaluated it is abandoned by inserting cement plugs at predetermined depths within the well to isolate various structures from each other and to seal off the well. The well head is then removed from the casing string at least 1 m (regulations) below the seafloor (mud line in Fig. 2.1) to minimize interference with fishing and other risks.

o Production

Drilling procedures are similar for production wells except the wells are not plugged and abandoned. Production intervals are selected in the wells and the casing perforated, i.e. holes placed in the casing over these intervals, to allow the flow of reservoir fluids into the well. Pumps are often installed to provide artificial lift of reservoir fluids to the surface. Groups of production wells may be connected to a common gathering point for handling reservoir fluids. Liquids and fluids are separated at the common gathering point and reservoir fluids are shipped to shore via a pipeline on the seafloor or by tanker. Gases can also be shipped by pipeline or tanker (after compression of the gas) . Small amounts of gas may be flared as well. Production platform(s) can be gravity-based like the Hibernia platform, floating-based like the proposed Terra Nova platform or permanent jack-up structures like those used in the shallow offshore offshore areas of the Gulf of Mexico .

2.2 Seafloor and shallow subsurface hazards/concerns

o Geohazards

A number of hazards associated with offshore petroleum exploration and development can adversely affect the environment and can halt exploration and production activity. These marine hazards occur in many basins throughout the world, although not all hazards listed in Table 2.2 occur in each basin. Iceberg scouring and iceberg movement on the Grand Banks are a serious hazard along the east coast that does not exist offshore Western Canada. On the other hand, the earthquake hazard on the west coast is significantly greater than that on the east coast and in the Beaufort Sea. Regulations require the potential for each hazard to arise must be assessed and procedures put in place to eliminate or minimize its impact. This section focuses on geohazards, hazards associated with geological processes (Table 2.2).

SEAFLOOR AND SUBSURFACE GEOHAZARDS AND CONCERNS
seismicity
faults
blowouts
shallow gas
overpressure
sediment transport
slope failure and stability
canyons and channels

Table 2.2: *Potential seafloor and subsurface geohazards that can affect oil and gas exploration and development*.

Each of these hazards can lead to one or more environmental problems. Table 2.3 list the consequences of the geological process and the associated environmental results. Unstable seafloor slopes can precipitate underwater landslides and debris flows. These events can damage or cause failure to pipelines, platforms and other seafloor facilities. The same is true for active faulting on the seafloor. The unexpected occurrence of high pressure shallow gas while drilling may lead to a blowout (the uncontrolled release of oil and gas from a well). The oil and gas released to the environment will contaminate the sea water. Hydrates are ice crystals formed from methane gas. If there is free gas beneath a hydrate layer (which forms a barrier or seal to upward gas flow) there is potential for a blowout. Hydrates are not expected in the Queen Charlotte region as water depths are shallow. Sediment transport on the seafloor caused by bottom currents , tides and wave action can induce rapid accumulation and/or erosion of seafloor sediments. Scouring and erosion of sediments can cause pipelines, platforms and underwater facilities to fail leading to the escape of hydrocarbons into the ocean. Sediment accumulation can cause burial of underwater facilities and pipelines making inspection and repair operations difficult.

Seismicity and formation overpressure (blowouts) are additional geohazards that must be considered. Seismicity in the Queen Charlotte region is significant so will be treated in a separate section. Overpressured formations are usually associated with deeper events and are not directly related to seafloor hazards. These zones are usually investigated using industry seismic data with modern processing techniques (Kan et al., 1999). Their existence is of considerable importance for safe drilling operations.

Other concerns associated with offshore petroleum exploration and development are related to topography and sensitive regions of the seafloor. Steep slopes, for example canyons and channels, should be avoided when planning the location of pipeline routes, drilling platforms and underwater facilities. Sensitive areas of the seafloor, for example known fish spawning grounds and other areas of unique biological diversity, must be avoided.

The potential geohazards in Table 2.2 can often be recognized from the character of their surface and subsurface expression on the seafloor. Table 2.4 lists some of the characteristics that can be used to identify potential hazards.

Sediments can liquify when prolonged shaking of the ground occurs during an earthquake. Certain characteristics are associated with liquifiable sediments. They usually have high porosity (amount of void space between mineral grains) and are fined-grain and poorly packed together. When shaking occurs, the grains can rearrange to fill the empty pore spaces. During the process some of the water occupying the pore space is expelled, allowing the the sediments to flow or liquify.

Shallow gas can be generated in-situ from the decay of recently deposited organic material. This biogenic gas is usually free to move upwards and escape onto the seafloor or into the atmosphere if it occurs in shallow sediments on land. The amount of gas contained in the pore space is typically a few percent of the total void space. Biogenic gas is usually at low pressure (although there are some sealing mechanisms that may lead to higher pressure biogenic gas being

Geological concern	Consequence	Potential result
seismicity	tsunamis	destruction of port facilities, platforms and Other near-shore facilities
	earthquakes	liquification of unconsolidated sediments
		damage and/or destruction of pipelines, platforms and seafloor structures
faults	local surface motion	damage and/or destruction of ripelines, platforms and seafloor structures
blowouts	high pressure gas and oil released from well	contamination of ocean and seafloor with hydrocarbons
shallow gas (hydrates)	high pressure gas and oil released from well	contamination of ocean and seafloor with hydrocarbons
	seafloor and slope instability	failure and/or damage to pipelines, platforms and seafloor facilities
overpressure	high pressure gas and oil released	contamination of ocean and seafloor with hydrocarbons from well
sediment transport	rapid accumulation and/or erosion of seafloor sediments	scouring and erosion of sediments causes facilities, pipelines and platforms to fail **-** can also cause burial of pipelines and seafloor facilities
slope stability	underwater landslides and debris flows	damage and/or failure to pipelines, platforms and seafloor facilities
canyons and channels	rough topography for seafloor structures	damage and/or failure of pipelines, platforms and seafloor faciilities

Table 2.3: *Consequences of seafloor geological hazards*

Hazard	Recognizable features
low strength or liquifiable sediments	can be recognized by sediment morphology, seismic character and grain size distribution
shallow gas	can be recognized by pockmarks on the seafloor, gas bubbles in water column, wipeout zones (absorption of energy), bright spots, gas columns in seismic data
overpressure	can be recognized as changes in seismic velocity associated with petroleum industry reflection seismic data
sediment transport	can be recognized from distribution of bed forms and erosional features on the seafloor, (eg. sand wave fields, channels, and scour indicators)
slope stability	can be recognized from past evidence of debris flows, landslides, and indications of shallow gas
canyons and channels	can be recognized by topographic features on seafloor
fragile regions of sea floor	can be recognized by relating different types of sea life to particular seafloor environments
faults	can be recognized by vertical and horizontal offsets on the seafloor and sometimes by seafloor reflectivity changes across the fault

Table 2.4: *Recognizable features of seafloor hazards*

formed in some instances) and normally not a hazard to drilling. Alternatively, gas leaking from hydrocarbon source rocks and reservoirs at depth can be trapped beneath shallow (less than 1000 m subsea) seals. The gas can build up with time to produce a high pressure, shallow gas reservoir. Shallow gas associated with these features can lead to serious drilling hazards.

The presence and intensity of shallow gas can be recognized from sidescan sonar and multibeam surveys as pockmarks on the seafloor where the gas escapes from the subsurface (Fig 2.9). Gas bubbles in the water column above the areas where the gas is escaping can sometimes be recognized on sidescan surveys . Seismic wipeout zones (zones where seismic energy is absorbed due to the presence of gas) can often be observed on shallow seismic surveys. Bright spots (large amplitude anomalies caused by the change in velocity associated with low velocity gas) is often an indicator of high pressure shallow gas (Fig 2.13).

Deep overpressured formations are a serious drilling hazard. These are investigated using conventional industry seismic data with modern processing techniques (Kan et al., 1999).

Sediment transport is caused by bottom currents, wave action and tides. The higher flow velocities can pick up sediments and transport them considerable distances. Once the water slows, the sediments drop out of the water column and are redeposited on the seafloor. Active sediment transport can be recognized from the distribution of bedforms and erosional features on the seafloor using multibeam, high resolution profilers and sidescan surveys (Figs 2.6 and 2.8). Placing objects on the seafloor will often change the distribution of bottom currents, leading to erosion and/or deposition of sediments around these objects. Serious scouring of sediments associated with objects placed on the seafloor (for example drilling platforms and pipelines) can cause these installations to fail due to uneven buildup of stress or redistribution of support.

Slope instability can be caused by shallow gas, earthquakes and gravity flow. Slope instability can usually be recognized by examining slopes for previous failures (deposition such as debris flows and landslide materials) using a combination of sidescan, multibeam and high resolution seismic techniques. Shallow gas associated with slope instability can be mapped using seismic techniques and sidescan as discussed earlier.

Active faults can cause failure of pipelines and other seafloor installations. They can be recognized by vertical and/or horizontal offsets in seafloor features or subsurface (seismic) reflectors and by changes in seismic reflectivity across the fault (Fig 2.12). Faults may be reactivated by stress buildup in tectonically active areas or by sediment loading. They can also be activated by changes in pore pressure caused by abnormally high tides and sea buildup due to wind).

Canyons, channels and steep slopes can be recognized from conventional and multibeam bathymetry. These areas should be avoided when planning pipeline routes, production platforms and other seafloor installations (Figs 2.5 and 2.6).

o Seismicity, earthquakes and faulting

The region which encompasses the Queen Charlotte Islands, the Queen Charlotte Fault, Dixon Entrance, Hecate Strait, Queen Charlotte Sound and northern Vancouver Island is a very active seismic area. Figure 2.2 is a map of the region showing the location of all earthquakes with magnitude $M > 5$ recorded between 1898 and 1981. In 1982 a local seismic network was installed in the Queen Charlotte region that could monitor earthquakes with magnitude $M > 1$. Figure 2.3 is a map of the seismic activity monitored with this network. The network was used from 1982 to when it was shut down in 1996. We can see from these two maps that most large earthquakes are located along or near the Queen Charlotte fault. There are several exceptions, such as the earthquake with magnitude greater than $M = 5$ in the northern part of Hecate Strait (Fig. 2.3) and several larger earthquakes located to the east of the Queen Charlotte Fault on or near Graham and Moresby Islands (Fig. 2.2).

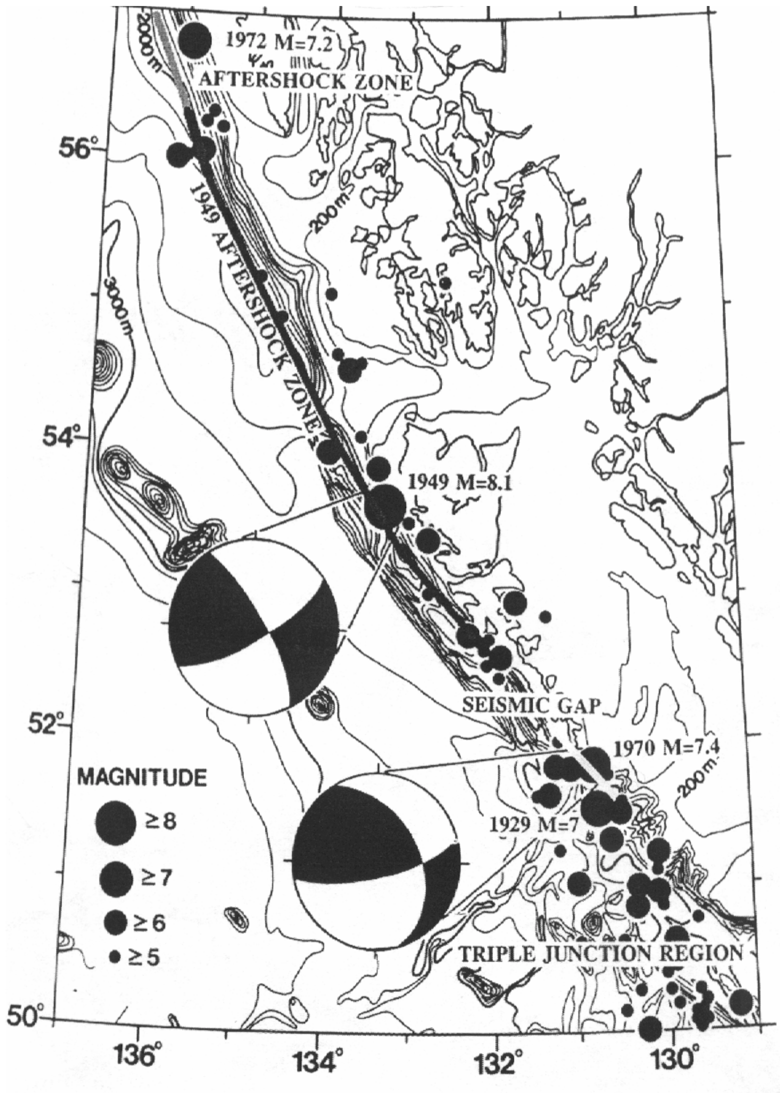

Figure 2.2: *Seismic events with magnitude M > 5 in Queen Charlotte region between 1898 and 1981 (from Bird, 1997).*

The shallow faults in the region, other than the Queen Charlotte Fault, are shown in Fig. 2.4 (Bird, 1997). In this Figure the dashed lines are possible extensions of mapped faults (Yorath and Chase, 1981) while the fault with the question mark was interpreted from reflection seismic data (Rohr and Dietrich, 1990; 1991) . There are no obvious correlations in this Figure between seismic activity and the shallow faults, with the possible exception of the northern part of the fault interpreted from reflection seismic. Limited seismic coverage at the present time precludes detailed mapping of offshore faults. The seismic sections in Figs. 1.7 and 1.8 illustrate that significant faulting does exist within Hecate Strait and that, with increased seismic coverage, the shallow faults within the area could be mapped in detail.

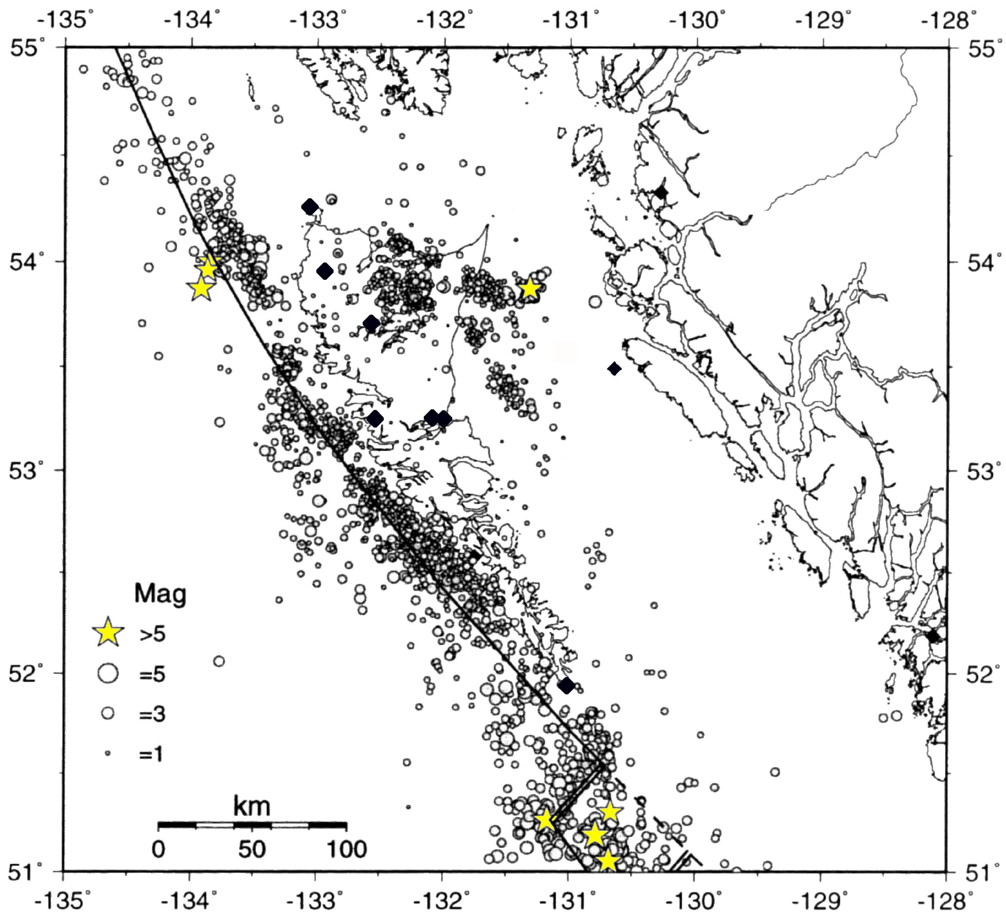

Figure 2.3: *Seismic activity (magnitude M > 1) in the Queen Charlotte region between 1982 and 1996. The diamonds show the location of several of the seismic network stations (from Bird, 1997).*

The cluster of seismic events on Graham Island north of the Sandspit Fault is more problematical since geological mapping in the area did not outline any significant shallow faults. Most likely the earthquakes are occurring along deeper faults that cannot be seen at the surface. On the other hand, active faulting does occur offshore as the example in Fig. 2.12 from the Tofino Basin off Vancouver Island clearly indicates.

The seismic activity in the area poses a serious environmental concern. Local earthquakes can cause tsunamis, activate shallow faults, cause underwater landslides and debris flows, and cause sediments to liquify. Large earthquakes along the Queen Charlotte Fault can cause similar environmental problems even though they are further away since they can be much larger and can

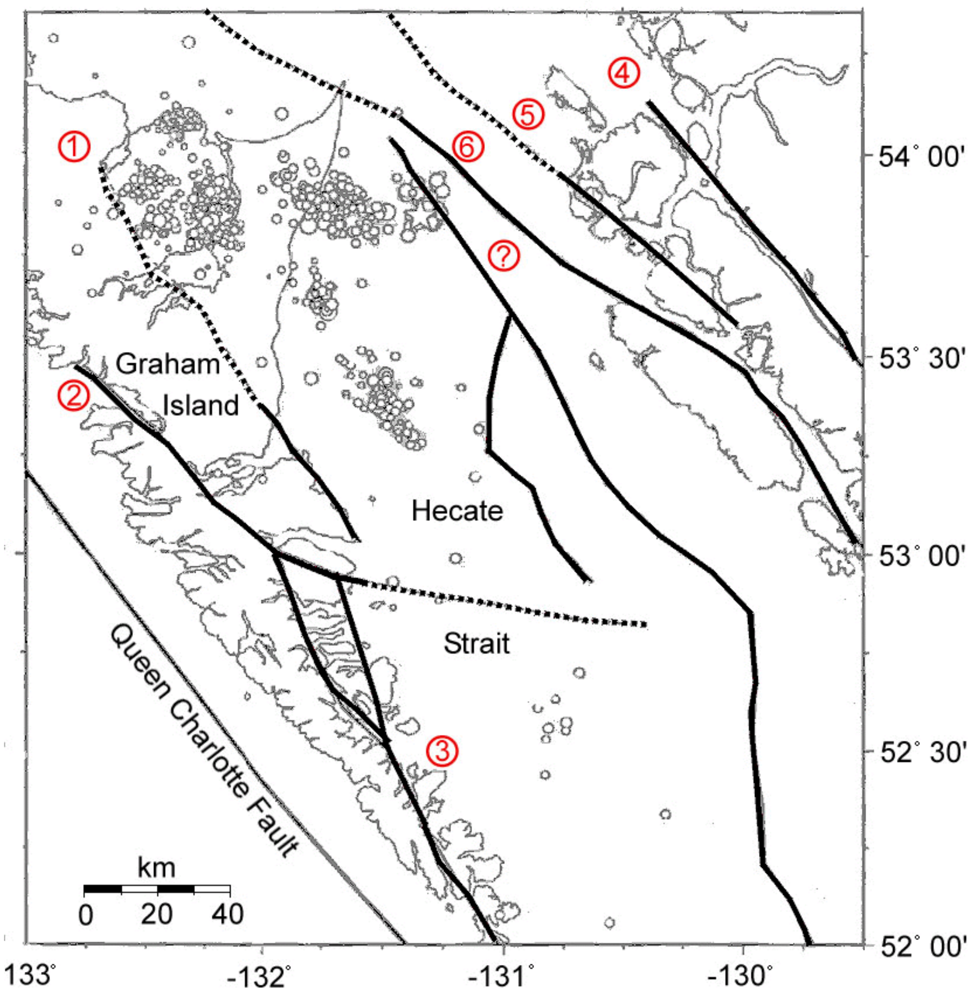

Figure 2.4: *Location of known and suspected shallow faults in Queen Charlotte region with overlay of seismic activity not associated with the Queen Charlotte Fault (Bird, 1997). Numbered faults are:* ***1****-Sandspit Fault,* ***2*** *- Rennell Sound Fault,* ***3****- Louscombe Inlet Fault,* ***4****- Grenville Channel Fault,* ***5****- Kitkatla Fault,* ***6****- Principe Laredo Fault, and* ***?****- fault proposed by Rohr and Dietrich from seismic interpretation (Rohr and Dietrich, 1990).*

cause shaking for longer periods of time. Structures have to be designed to withstand the significant ground motion generated by these earthquakes. Probabilistic studies have been carried out to determine the expected ground motion for different events (along the Queen Charlotte and Sandspit Fault Zones (Weichert and Hyndman, 1982) that provide estimates of ground motion for designing structures to withstand earthquakes in this region.

2.2 Seafloor and Shallow Sebsea Hazards/Concerns

o Tidal and current impacts

Since the early 1980's when a large number of environmental studies were undertaken in the offshore areas of the Queen Charlotte Islands, much research modeling and some additional data acquisition has been completed. Some of the early current observation (recording) stations, occupied by various government agencies, are represented on Fig. 3.3 Tide data has been recorded at numerous shore locations in this area and can occasionally provide real-time tide observations as well as the historical/prediction of data to mariners in the region. This type of information is primarily collected and provided by the Canadian Hydrographic Service.

Geohazards resulting directly from prevailing environmental conditions can occur on the seabed level where localized bottom currents can drive sediment transport activity to create over steepened underwater slopes (through accumulation and/or erosion), scouring, undermining of seabed installations and foundations as well as burial of seabed structures. Seafloor current conditions are often responsible for the presence or absence of various sediment types on the seabed as well as the micro topography and sedimentary bedforms present (e.g., scour depressions, sandwave fields and areas of lag deposits). In coastal areas with large tidal ranges, many historical underwater slope failures have been triggered by the effects of the changing sediment pore pressures during the time of lower tide levels (drawdown phase). This situation occurs more frequently in the fjord areas of B.C.

The following provides a brief overview of tidal ranges and tidal and non-tidal current conditions in the Hecate Strait and Queen Charlotte Sound region.

The tidal wave sweeps northward along the coast of North America. Due to its speed of over 700 km/h the delay between arrival of high or low tide near the north end of Vancouver Island and Langara Island (the most northerly point of the Queen Charlotte Islands) is only about ½ hour.

The tide near the British Columbia coast and off its shores is mixed, mainly semi-diurnal, i.e., there are two high tides and two low tides in one lunar day (approx. 25 hours), although there is a distinctive height difference between successive high, or low, tides.

At Cape Scott, on the northern tip of Vancouver Island, and at Cape St. James, on the southern tip of the Queen Charlotte Islands, the large tide range is about 4.7 m. As the tide progresses northward along the western side of the Queen Charlotte Islands, its large range increases slightly to 5.3 m at Langara Island.

As the tide enters Queen Charlotte Sound, the range increases towards the shores of the mainland and increases further as the tide enters Hecate Strait and proceeds northward through the strait. The large tidal range in Queen Charlotte Sound is 5.0 m, increasing in Hecate Strait to 5.5 m near Goose Island and to 6.2 m near the north end of Aristazabel Island. When the tide reaches Chatham Sound, the range has already increased to 7.6 m. On the east coast of the Queen Charlotte Islands, the range increases form 4.7 m at Cape St. James to 6.4 m near Juan Perez Sound and also in Selwyn Inlet. Due to the extremely inhospitable shoreline on the east coast of Graham Island not much is known about the tidal range, although it is assumed that the range increases as the tide travels north.

In constricted areas near the shore and especially at the head of long fjords or inlets, the tidal range increases significantly. For example, the range at Bella Coola near the head of North Bentinck Arm is 5.9 m, at Ocean Falls in Fisher Channel it is 5.6 m, at Kitimat 6.4 m, Kemano 7.0 m, Prince Rupert, 7.7 m, at the head of Observatory Inlet 7.8 m and finally at the head of Portland Canal 8.1m.

Not much is known about significant currents in the open ocean off the west coast of the Queen Charlotte Islands, but from the few observations available, it is assumed that the currents do not exceed about 2 knots (100 cm/sec).

In the outer reaches of Queen Charlotte Sound, surficial currents consist of clockwise rotary tidal streams, where principal flood tides are to the northeast at a maximum of about 1 knot (50 cm/sec), while principal ebb tides are to the southeast at the same speed. Near the shore the currents become more rectilinear.

Surface tidal currents in Hecate Strait are rectilinear, with a maximum speed of less than 2 knots (100 cm/sec) the flood direction is northeast, while the ebb flows to the southwest.

Influences of wind on the water surface must be taken into account in order to obtain a representative picture of the total currents. It is usually impossible to predict wind-induced currents far in advance, but one can make assumptions from prevailing seasonal conditions. It is thought that typical speeds of wind-induced currents are in the order of 3% of the wind speed averaged over several days. This assumption is thought to be especially valid for the transport of a layer of oil floating on the water surface.

It must be noted that few seabed level current observations have been historically collected in this region and for the most part, this information is derived from current observation data collected at the sea surface or at multiple levels above the seabed. Mathematic modeling of the upper level current regimes is often used to derive reasonable seabed level current flow characteristics. These data could aid in the study of erosional and depositional conditions in the particular site area.

2.3 Seafloor and subsurface techniques for geohazard mapping

Features related to geohazards (Table 2.4) can often be identified using a combination of geophysical techniques, remote sensing tools and sediment sampling. In this section we shall discuss the use of these methods for mapping and identifying these features.

o Conventional and multibeam bathymetry

Conventional bathymetry or echo sounding surveys record precise water depth along the ship's track. A high frequency acoustic pulse is generated by a transducer attached to the ship's hull. The frequency of the pulse is usually between a few tens of kiloHertz to a few hundreds of kiloHertz. This pulse propagates outward from the ship, eventually reaching the seafloor where it is reflected back towards the ship. The reflected pulse is detected by the same transducer and the two-way travel time (the time for the pulse to travel to the seafloor and back) is measured and converted to water depth from the simple formula;

Water Depth = water velocity x one-half the two-way time

where the water velocity is a known value.

A bathymetric map can be constructed by plotting water depth as a function of position and then contouring the values. Global Positioning Systems (GPS) are now available that can accurately locate the ship's position to within a few metres. The combination of GPS and digital acquisition systems allows these maps to be produced electronically. An example of a topographic and bathymetric map from the Queen Charlotte region is given in Fig. 2.5. The seafloor topographic variations shown are based on a synthesis of existing conventional bathymetric data for this region.

Conventional bathymetry has sufficient resolution for regional mapping. It does not effectively provide detailed or high resolution imaging of the seafloor. The spatial and depth resolution is limited by several factors: (1) large spacing between ship's tracks, (2) the cross-sectional area of the seafloor the acoustic pulse interacts with (determined by the pulse frequency and water depth), (3) frequency of the pulse, and (4) the mathematical methods of generating contour maps from sparsely sampled data. Multibeam or swath bathymetric techniques overcome some of these limitations.

Multibeam mapping uses transducer arrays to transmit and receive acoustic information, with up to 120 individual beams energizing a small portion of the sea floor (Orange et al., 1999). The combination of beams provides a "swath" of data. These systems have much higher spatial resolution, with individual beams sampling a much smaller portion of the sea floor. The large sensor array permits bathymetric soundings to be obtained along a wide swath on each side of the ship's track at a high sampling rate (proportional to water depth). The width of the swath is determined by the actual dimensions of the array, the frequency of the acoustic transducers and the average depth of water. A graphic depiction of a typical swath acoustic beam spread is shown in Fig 2.6. By carefully choosing the ship's tracks to allow overlap between swaths a mosaic is formed that can be used to generate a bathymetric map with a significantly higher resolution than conventional bathymetry.

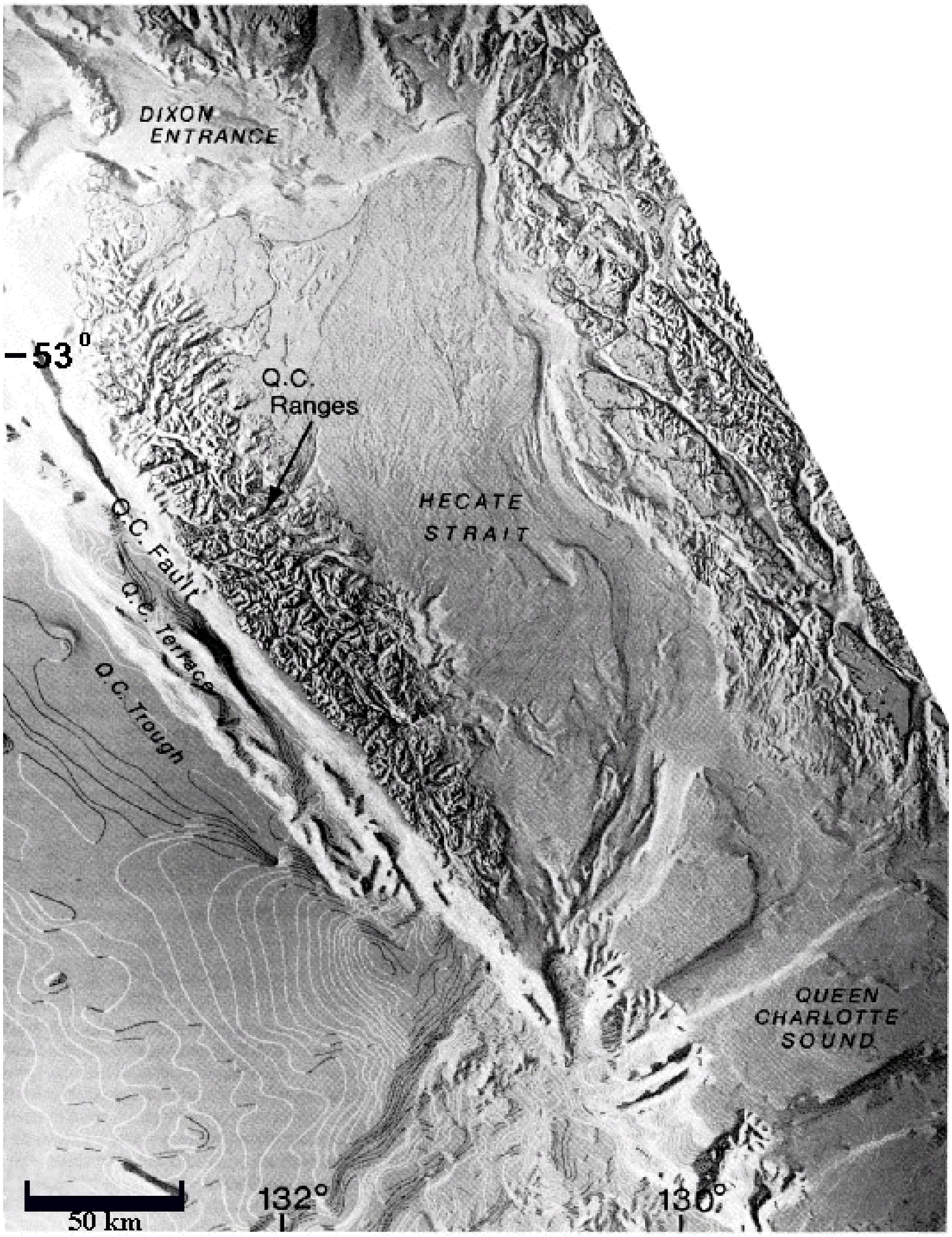

Figure 2.5: *Oblique shaded-relief depiction of topography-bathymetry for the Queen Charlotte area (from Sawyer, 1989).*

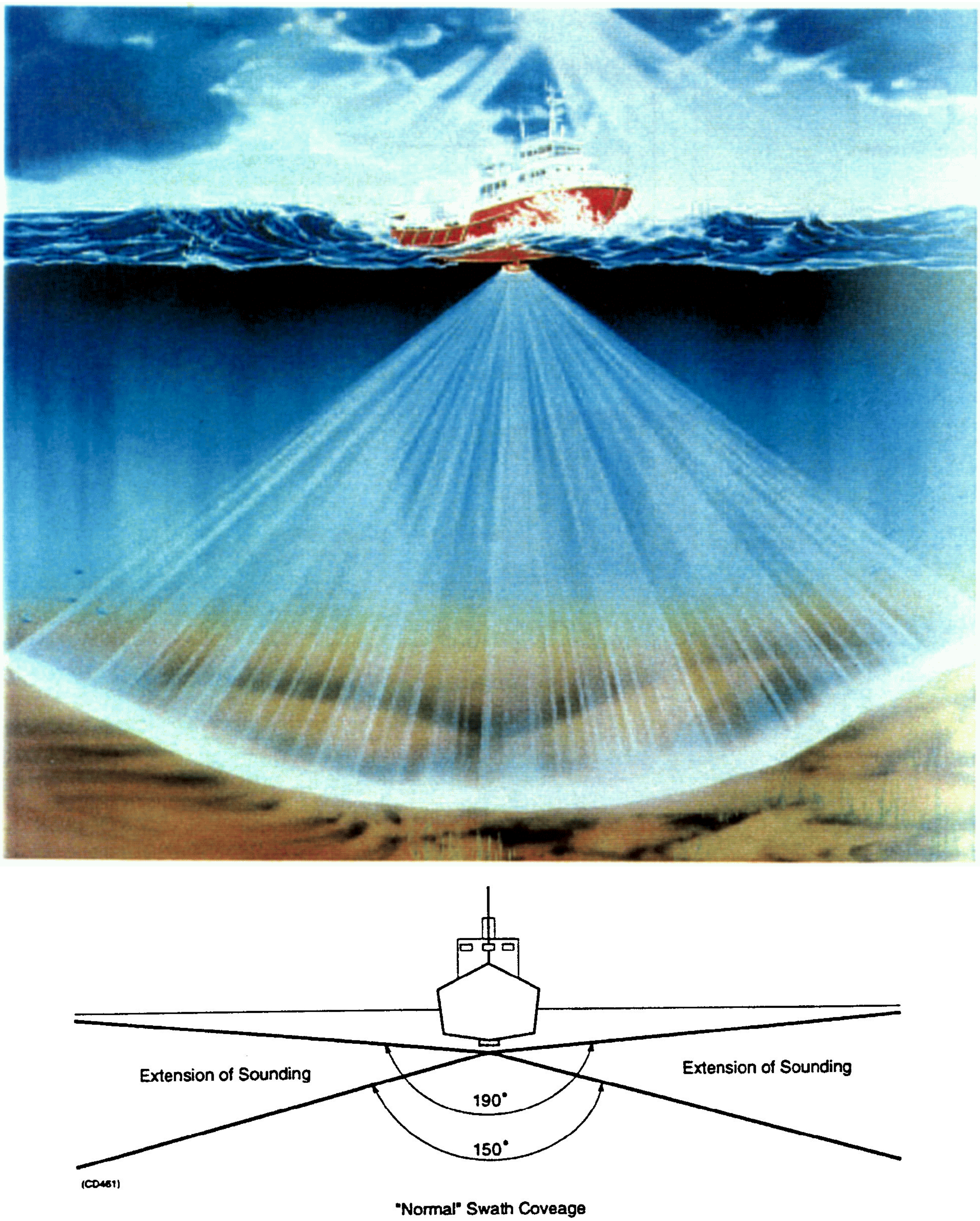

Figure 2.6 *Depiction of a swath or multibeam bathymetric survey installation and typical acoustic beam coverage (from Simrad Mesotech).*

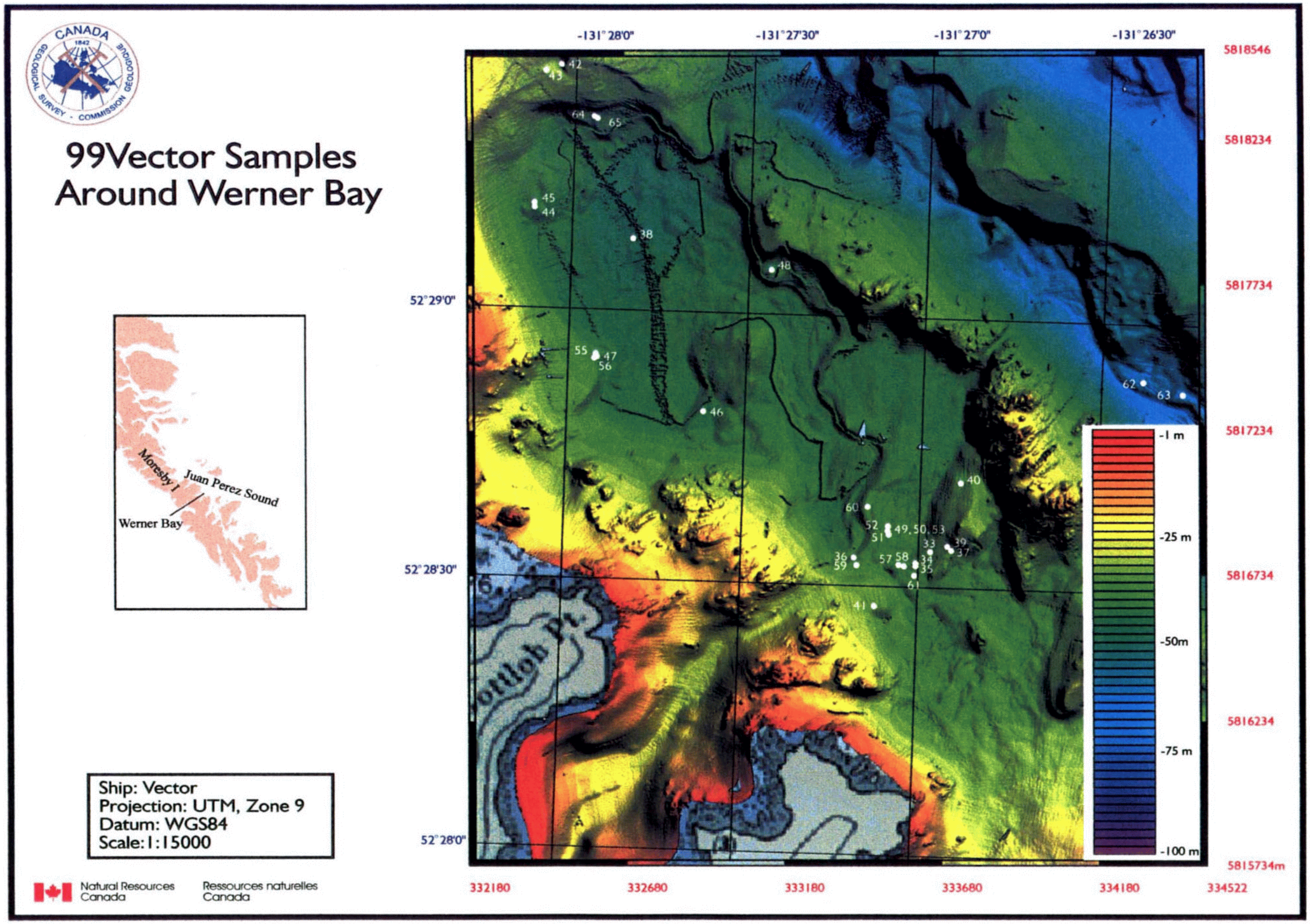

Figure 2.7 *Colour-banded detailed bathymetric data collected at a nearshore study area in the Queen Charlotte Islands using a high frequency multi-beam system. (From Josenhans and Harding, 1999)*

Multibeam systems are designed with specific water depths in mind. The two systems of most interest for the Queen Charlotte region are; (i) mid-frequency systems, with a frequency between 30 and 50 kHz which maps the seafloor at water depths between 50 m and 3500 m and (ii) high-frequency systems, with a frequency between 95 and 100 kHz which maps the seafloor at water depths between 100 m and 1000 m. Different multibeam systems have different beam configurations, which will affect the swath width. Swath widths will also change as a function of depth due to attenuation of the outer beams. Typical swath widths for mid-frequency systems are 5 to 7 times water depth in 50 to 500 m of water, 3 to 5 times water depth in 500 to 2000 m of water, and 2 to 3 times water depth in 2000 to 3000 m of water. As expected, the resolution also decreases with increasing depth. Figure 2.6 is an example of a multibeam survey carried out near Juan Perez Island, Moresby Island by Josenhans and Harding (1999) for Parks Canada.

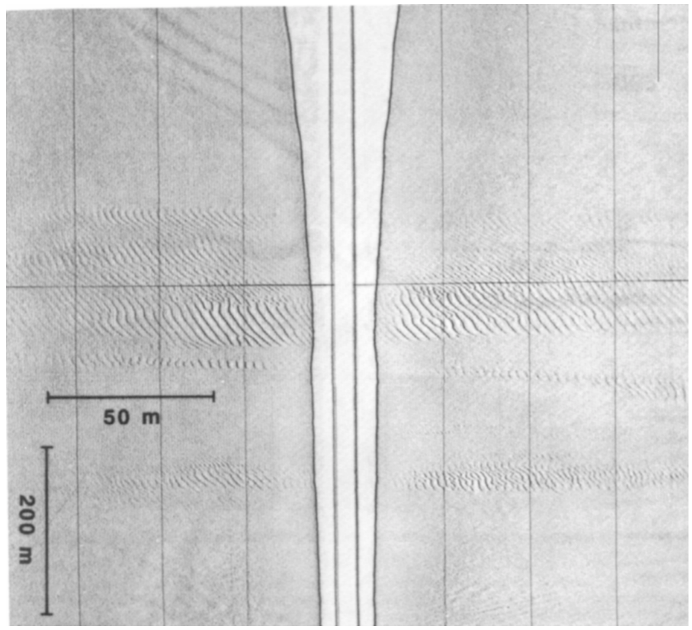

Figure 2.8: *Sonograph of sand waves on Laskeek Bank in Hecate Strait (from Barrie and Bornhold, 1989).*

o Sidescan sonar

Bathymetric maps are generated from the two-way travel times measured with an echo sounder or multibeam system. In addition to bathymetry, sidescan sonar and multibeam systems can also measure acoustic reflective properties, i.e. changes in amplitude, phase and frequency content of the transmitted pulse caused by reflection from the seafloor. Acoustic reflectivity provides information on material properties of the seafloor (sediment type, bedrock. pockmarks, iceberg scours, sand waves and other sea floor features as well as man-made debris such as shipwrecks). Different materials on the sea floor will have different reflective properties. For example the reflected signal from hard bedrock will be more intense than the reflected signal from soft mud. Sidescan sonar and multibeam systems are designed to measure and display reflective properties along a swath on each side of the ship's track. Sidescan systems are usually towed in a "fish" near the seafloor while multibeam systems are mounted on the ship's hull. The width and spatial resolution of the sidescan system depends on the frequency and duration of the transmitted acoustic pulse, the cross-sectional area of the outgoing pulse and the height of the transducer array above the seafloor. Figure 2.8 is an example of a sidescan sonar image (sonogram) of the sea floor showing sand waves on Laskeek Bank in Hecate Strait and Fig. 2.9 is an example of a sonograph from the east coast of Canada showing gas pockmarks on the seafloor.

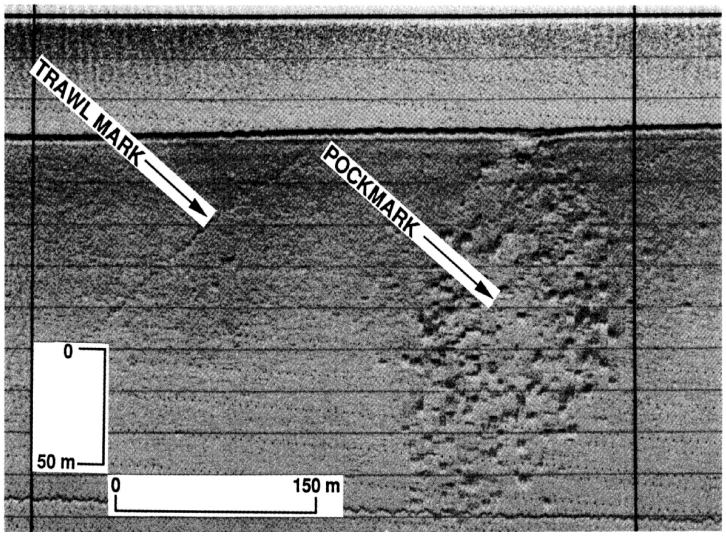

Figure 2.9: *Sonograph of gas pock marks from the Scotian Shelf (from Fader, 1991)*

o High resolution shallow seismic

High resolution seismic methods are used to map the subsurface geology to a depth of several hundred metres beneath the seafloor. This technology maps the shallow subsea geological structures and stratigraphy, for example debris slides associated with slope failures, faults, gas columns, gas and hydrate zones as well as sediment deposition.

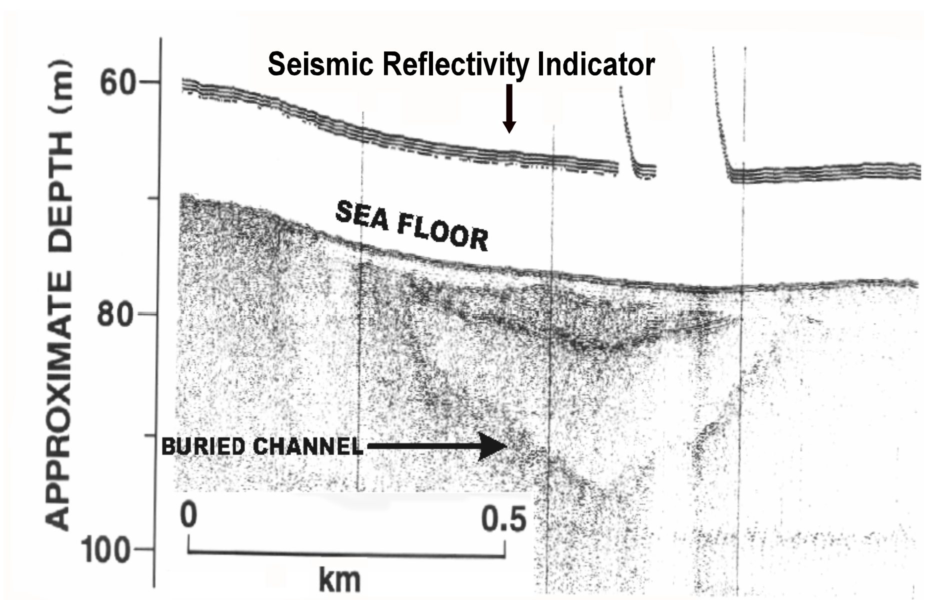

Figure 2.10: *High resolution seismic section showing a buried channel cut into Hecate Strait sands and gravels (from Barrie and Bornhold, 1989).*

This methodology uses an acoustic pulse (wavelet) as an energy source but the frequency content is lower than that used in sidescan and multibeam systems. Typical sources include pingers, boomers, sparkers, airguns and water guns. The acoustic source sends out a signal (wavelet) travelling outward from the source. When this signal reaches a boundary where there is a change in acoustic impedance, the product of velocity and density, part of the signal is reflected back towards the surface and can be measured using one or more hydrophones (pressure transducers). The large contrast in acoustic impedance at the seafloor produces a strong reflection. The air-water interface also produces a strong reflection so that the acoustic signal can reflect back and forth between these two surfaces, leading to water bottom "multiples" . An example of a water bottom multiple is given in Fig. 2.12. The hydrophones measure the amplitude and phase of the acoustic signal as a function of time (time zero is when the acoustic source fires). These relatively high frequency sources provide high resolution data but limited penetration as there is a tradeoff between depth of penetration and the seismic resolution achieved

Single channel seismic systems measure the acoustic signal using a single hydrophone array having multiple sensors summed into a single output signal. They are the most common of the high resolution systems (pinger, boomer and sparker systems all measure the acoustic signal using a single channel hydrophone or receiving transducer). The source and receiver of some systems are towed close to the seafloor such as sidescan while others have the source and hydrophone towed near the sea surface at the rear of the ship just beyond the influence of the propellor and wake.

Several examples of single channel seismic data are provided in Figs. 2.10 to 2.12. Note the extremely high resolution of these system as well as the limited depth of penetration.

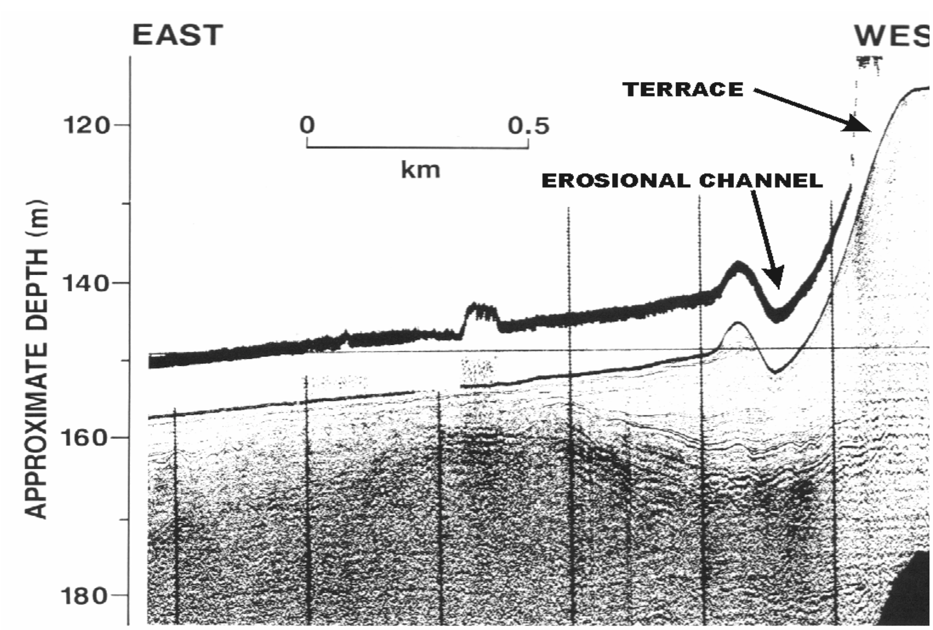

Figure 2.11: *High resolution seismic section showing a wavecut terrace in Hecate Strait with an erosional channel at the base (from Barrie and Bornhold, 1989).*

High resolution multichannel seismic systems are similar to the survey systems used by industry for petroleum exploration except that the source is usually smaller (higher frequency) and the towed array of hydrophones is shorter. These systems use one or more air or water guns for the seismic source which are towed at a shallow depth (around 1 to 3 m). The volume of these guns is much less than those used for exploration seismic surveys so that he frequency is higher. This provides higher resolution but limits the depth of penetration in the seafloor geology to less than approximately 1000 m. An array of close-spaced hydrophones is towed behind the ship to record the reflected seismic energy as a function of time. Multichannel systems provide more options for processing and enhancing the data. An example of a multichannel seismic section showing shallow high pressure gas is given in Fig. 2.13.

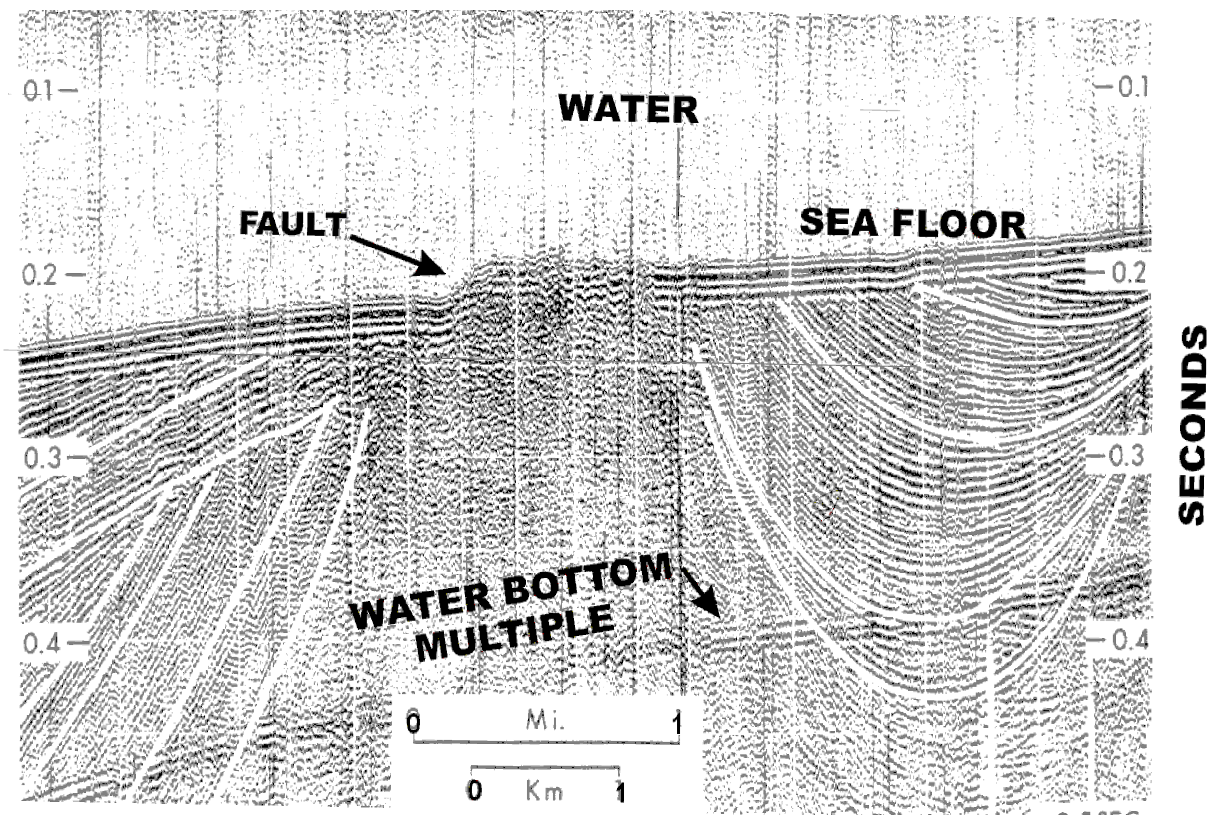

Figure 2.12: *Sparker seismic section showing an example of a fault in the Tofino Basin penetrating the seafloor. Note the disruption of the reflectors in the area of the fault and the water bottom multiple (from Shouldice, 1971).*

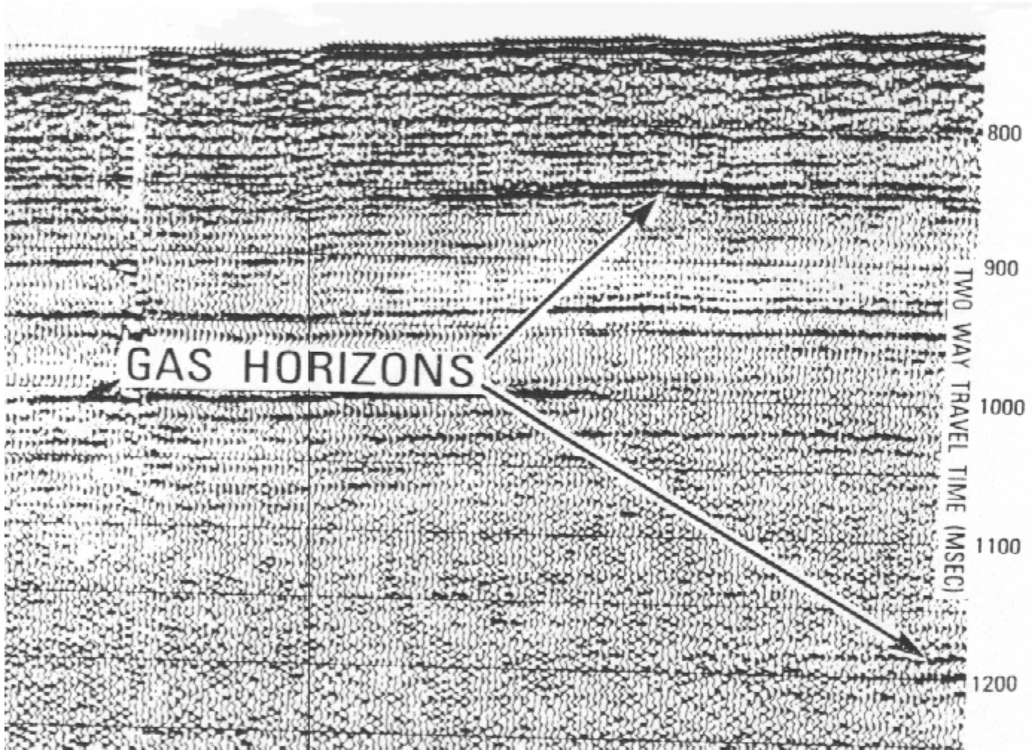

Figure 2.13: *Example of a multichannel seismic survey showing shallow gas zones (called bright spots due to he increased amplitude of the signal) in the Labrador Sea (from Chevron Canada, 1982).*

o Sediment sampling

Samples of seafloor sediments collected using special sampling devices from the ship provide a chance to examine and test the material directly. Visual inspection provides information on sediment type, organic content and biological diversity. A typical example of core sediment is shown in Fig. 2.14. The type of sediment deposited on the seafloor determines the environment for benthic habitats. Material collected can be analysed for grain size distribution providing input for liquefaction studies. Often material contained in the samples can be used for radioactive isotope dating; thus giving information on sediment age. Geochemical analysis (both organic and inorganic) can be carried out on samples to investigate the geochemical composition and mineralogy of the material and to ascertain any particular contaminant content. Gas content (volume and composition) of samples can also be determined. In addition, sidescan and multibeam reflectivity can be calibrated by comparing their acoustic responses to the seafloor sample classifications.

Gravity, piston and vibrocore core samples collected subsea using specialized drilling equipment on the ship provide valuable data on sediment processes. Sediment analysis techniques

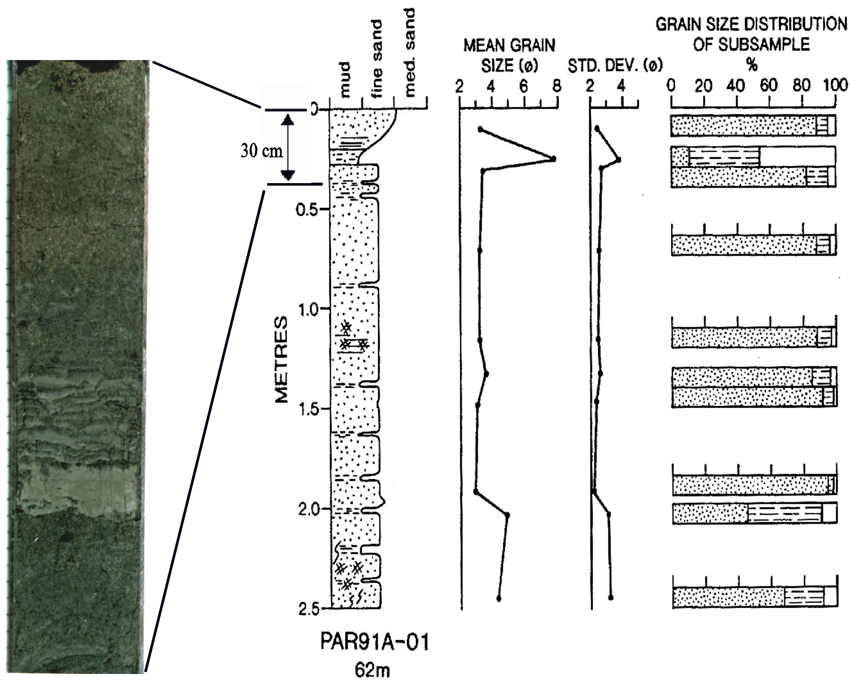

Figure 2.14: *Picture showing a typical 30 cm section of shallow piston core sample with descriptive and analytical results.*

provide information on can be carried out to generate a picture of how sediment characteristics change with depth. The interpretation of high resolution seismic data can be calibrated by comparing specific reflectors with changes in sediment type and corresponding physical strength characteristics.

o Geotechnical studies

Geotechnical studies provide information on engineering properties of seafloor material such as shear strength which is a measure of a material's ability to withstand deformation or shearing forces. Stiff material is less likely to deform under loading than soft material. Such engineering information provides important input for designing large structures on the seafloor since these structures may cause significant loading of the sediments.

Geotechnical properties can be determined in laboratories using samples collected on the seafloor, by special probes inserted into seafloor sediments, and indirectly by remote measurements (for example resistivity and shear wave velocity) The cone penetrometer is a probe that is “pushed” into soft sediments using fixed-energy hammer blows or a hydraulically driven steel coils as the energy source. Softer, i.e. weaker, sediments, require less “blows” or driving pressure to penetrate a fixed distance than sediments with a larger shear strength. The Cone Penetrometer Test (CPT) provides measurement of in-situ sediment properties which are used by geotechnical engineers to define bearing strengths and other characteristics.

Engineering properties can only be inferred from remote sensing methods. The bottom-towed marine electromagnetic (MEM) system (Mosher and Law, 1996) measures the resistivity of the shallow sediments beneath the seafloor as a function of depth and mathematically converts the resistivity to an equivalent porosity (amount of empty or void space in the sediment).   Sediment porosity is an indirect indicator of shear strength since higher porosity sediments usually have lower shear strength.

Shear wave velocity can be measured as a function of subsea depth using a special shear wave source and receiving array on the seafloor. Shear waves (S-waves) are seismic waves that propagate with a shearing motion perpendicular to the direction of propagation; these waves travel slower than the compressional waves (P-waves) used in conventional seismic profiling systems discussed earlier The shear modulus of the sediments can be computed from the shear wave velocity if the density of

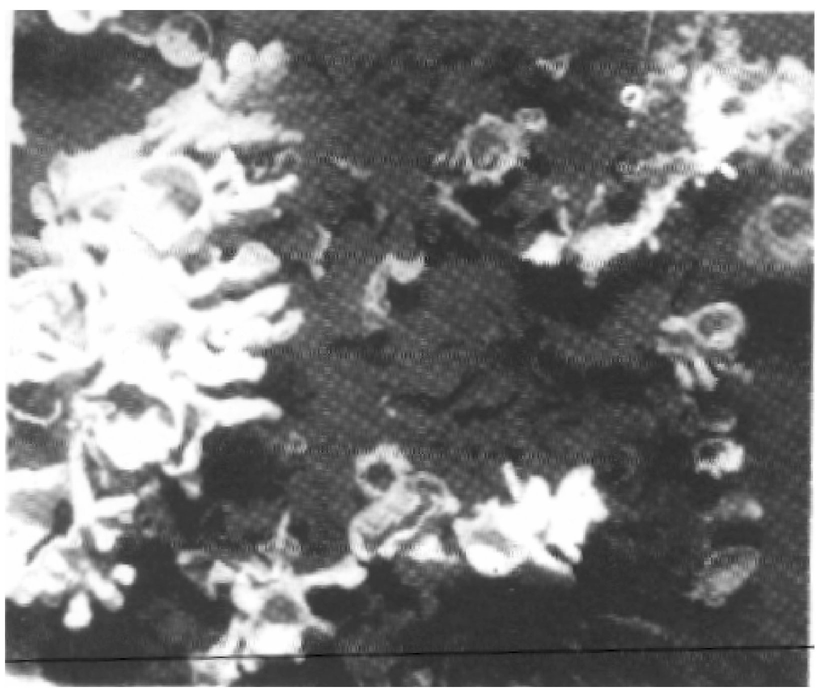

Figure 2.15: *Siliceous sponges in Hecate Strait with sediment clotted sponges in centre (from Conway et al. 1991)*

the material is known. This parameter is used extensively to assess susceptibility to liquification under seismic load.

Cone penetrometer and remote measurement of shear strength are rapidly becoming a standard technique in seabed engineering studies. Current industry practice has been to collect seafloor samples and cores and have them analysed for geotechnical properties in laboratories. Often both techniques are required at various stages of a project.

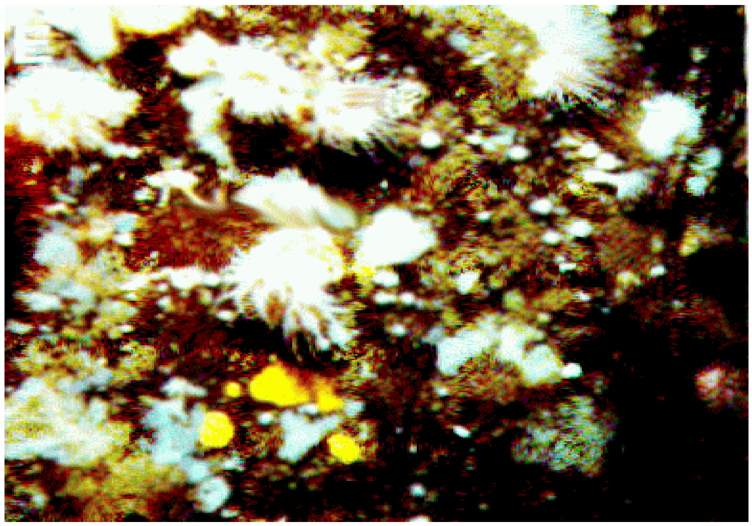

Figure 2.16: *Seafloor photo of fauna from Bay d'Espoir, East Coast, Canada (from Haedrich and Gagon, 1991)*

o Remotely operated vehicles (ROV's)

Video and still cameras provide visual information of plant and animal life on the sea floor, morphology of sea floor sediments (for calibration of acoustic backscatter) and other ground-truthing information (for example visual information on pockmarks and gas discharge activity above pockmarks). These cameras are usually mounted on special undersea vehicles that operate on the seafloor but are run remotely from the surface support ship. Remotely operated vehicles can also be used to collect marine plants and animals, sediment samples, boulders, coral and even man-made objects. Figs. 2.15 and 2.16 illustrate the types of images that can be collected.

2.4 Impact of geohazards on socio-economic issues

During the 1980's consideration was given to lifting the moratorium on exploration drilling for oil and gas offshore British Columbia. At that time a five-person panel was appointed to hold information meetings and public hearings throughout northern coastal British Columbia . Chevron Canada Resources Limited and Petro-Canada were the industry proponents, although Petro-Canada withdrew in 1984. At that time both companies submitted detailed environmental assessment and socio-economic reports (Chevron, 1982, 1985; Petro-Canada, 1983) and the Panel submitted a report in 1986 (West Coast Offshore Exploration Environmental Assessment Panel, 1986). These reports cover a multitude of socio-economic issues. Consequently this section shall only discuss those socio-economic issues uniquely related to geohazards.

o Population

The population in the region is scattered throughout a number of small villages and towns as well as several larger cities. Figure 2.17 is a map showing the main population centres in and around the study area. The largest centres are at Prince Rupert and Kitimat on the mainland and Port Hardy on the east coast of Vancouver Island. The potential effects from oil spill events related to seafloor geohazard conditions (Table 2.3) are damage and/or failure to pipelines, platforms and other seafloor facilities. The impacts these may have on the local population will depend on the location of the damaged facility relative to population centres and the rate and volume of the product spilled or lost. Potential oil spills caused by these hazards could seriously affect the economy of local communities through temporary closure of commercial and sport fishing grounds and perhaps loss of tourist and recreational income. Degradation of the local environment may have longer term economic affects related to fish spawning grounds and shellfish areas. On the other hand, a history of such undesirable events shows that the damage caused by these spills has led to short-term local employment related to oil spill cleanup at sea and on beaches as well as providing opportunities for the local communities to furnish supplies, transportation and accommodation during cleanup and repair of damaged facilities.

o Fishing activity and spawning areas

Fishing activity in the region is a combination of commercial and sport fishing. Salmon are the main species sought by sports fisherman but the revenue from sports fishing in the area has dropped due to the decrease in the salmon population. Commercial fishing activity includes shellfish, groundfish and fin fish. Salmon forms the largest component of the north coast commercial fisheries but the catch is decreasing (except for Sockeye) due to diminishing stocks of chinook, coho, pink and chum. Different species of fish/shellfish tend to concentrate in particular areas. As an example, Figs. 2.18 and 2.19 show local salmon and groundfish fishing activity and spawning areas in the Queen Charlotte region. Salmon can be found throughout the entire region due to their migratory nature (Fig. 2.18). Although many species caught in this region have declined, the distribution of fishing and spawning grounds is expected to be similar to those shown in earlier reports.

The impact of oil spills on the fishing activity and on the spawning grounds is similar to that discussed earlier under population. Commercial and sport fishing may have to be temporarily suspended during cleanup of oil spills. Longer term closure of crab and shrimp grounds may be required if oil is deposited on the sea floor in these areas. Future fish stocks may be reduced over a period of time if oil spills occur in important spawning grounds.

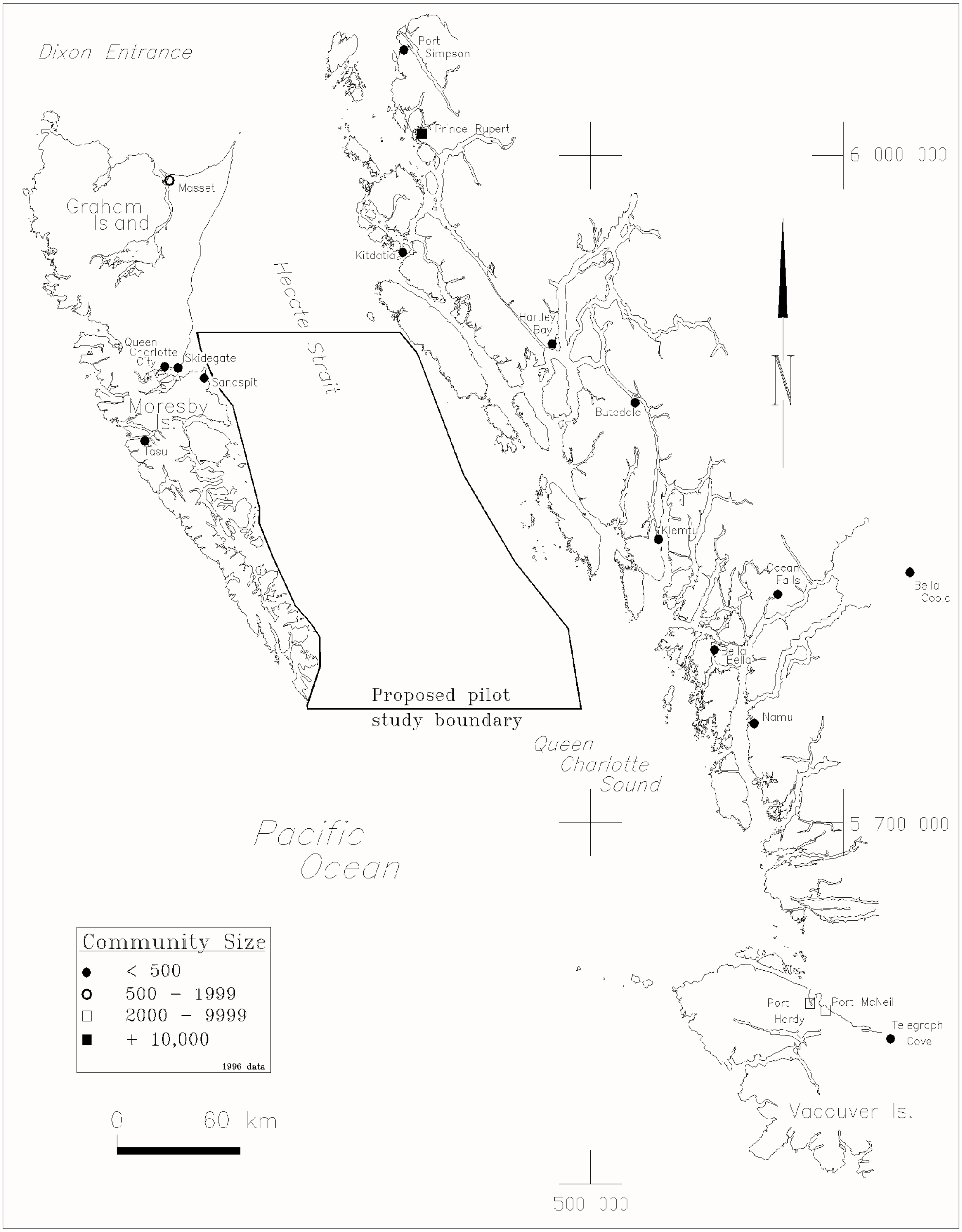

Figure 2.17: *West coast reference map showing population centres.*

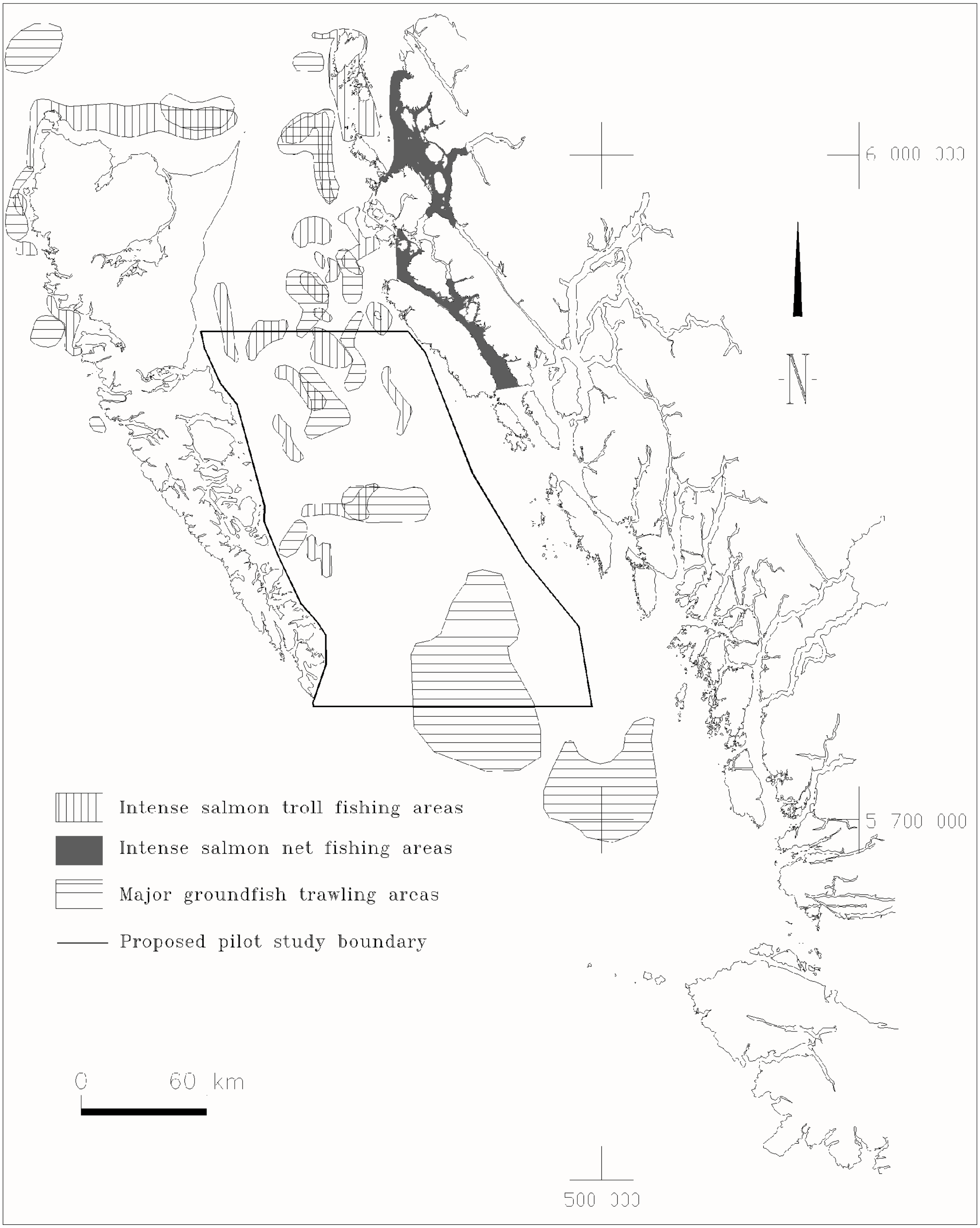

Figure 2.18: *Intense trolling, net fishing and groundfish trawling areas (Source: Environmental Protection Service, 1978a,b).*

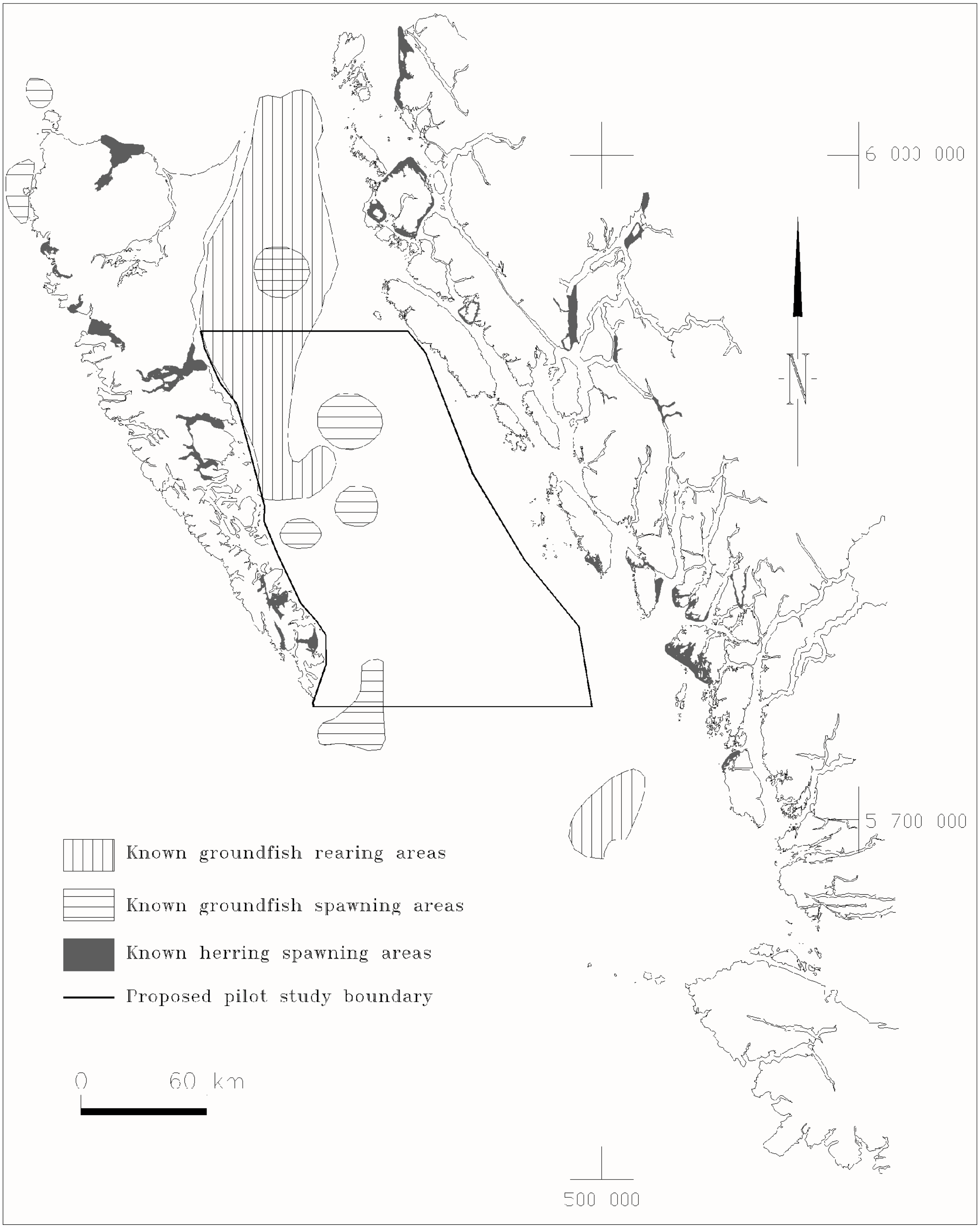

Figure 2.19: *Major groundfish and herring spawning and rearing areas (Source: Environmental Protection, 1978).*

o Sensitive areas

There are 13 proposed protected areas, 67 first nations reserves, 9 parks and 4 ecological reserves in the region (Table 2.5). The impact of oil spills on these areas would be similar to those described above but at the same time quite different. Oil occurring on beaches in marine parks caused by spills would certainly be higher profile than on other beaches and oil reaching ecological reserves from spills could be very damaging to these sensitive areas. The location of some of these sensitive areas are shown on the map in Fig. 2.20.

2.5 Pilot study area

The limited scope of this report did not allow for the development of maps showing potential geohazards within the area. In order to fully appreciate the extent and role of geohazards within the region we recommend carrying out a detailed pilot study. This section discusses the selection of the pilot area and its relevance to exploration potential and socio-economic impacts. The output of the pilot study would be; (i) a series of maps showing the distribution of potential geohazards, (ii) a more thorough discussion of the techniques used to map the seafloor and subsea geology and (iii) a discussion of how the particular hazards in the area could manifest themselves during petroleum exploration and development.

The pilot study will produce regional scale maps showing potential marine geohazards. On the east coast regional mapping and interpretation of potential hazards have been carried out by the federal and provincial governments for nearly 30 years. Such regional information has helped the federal and provincial governments (and the two existing Petroleum Boards on the east coast) in their risk management and decision making regarding exploration and exploitation activity in the offshore and coastal zones. Similar studies on the west coast would provide the level of information needed for good decision making.

Industry has traditionally relied on these regional studies. Their site-specific surveys for well and platform locations can then be placed within the regional studies for the area to provide an overall hazards picture. Such regional studies also enables the Petroleum Boards to make better decisions regarding risks management.

o Relevance to exploration potential

The hydrocarbon potential of the Hecate and Queen Charlotte Basins has been described in Section 1.3. Cretaceous, Miocene and Pliocene oil and gas exploration plays are defined by the Geological Survey of Canada in their recent hydrocarbon assessment of the region (Hannigan et al., 1998) and cover the entire Queen Charlotte and Hecate Basin area. The hydrocarbon potential of the basins has not been prioritized except for the Cretaceous play where the basal sand unit within the Haida Formation has been highlighted (Fig. 1.9).

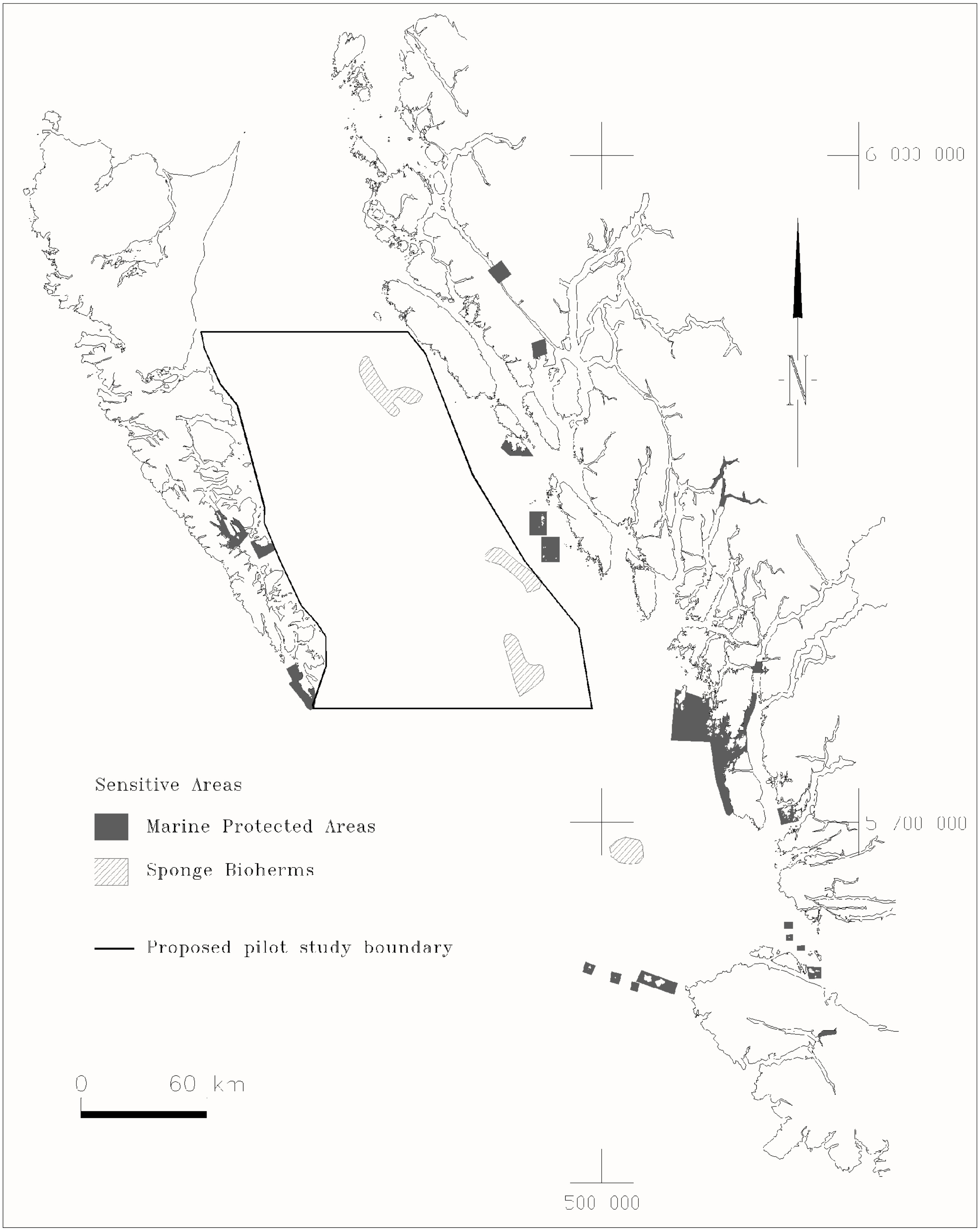

Figure 2.20: *Distribution of Marine Protected Areas (MPAs) and known areas of Holocene sponge bioherms (Source: Conway et al, 1991).*

LOCATION	FIRST	ECOLOGICAL	PARK	PROPOSED
Hartley Bay	1			
Kitimat	3			
Douglas Channel	3			
Kitlope			1	
Fjordland			1	
Klemtu	1			
Moore Is.	1			2
Dewdhey Is.				1
Bella Bella	8		1	
Dean Channel	4		1	
Burke Channel	1			
South Bentnick	1			
Bella Coola	1			
Haida Gwaij	2	1	2	3
Port Simpson	6	1	1	1
Dundas Is.	8			Entire area
Nob Group	1			
Prince Rupert	3	1	2	
Stephens Is.	1			3
Kitkatla	1			
Pitt Is.	9			
Banks Is.	3			
Dome Hill Is.	1			
Gil Is.	3			
Compania Is.				Entire island
Princess Royal	4	1		1
Totals	**67**	**4**	**9**	**13**

Table 2.5: *Summary of protected coastal areas and parks between Port Simpson and Bella Coola (from Ecotrust Canada).*

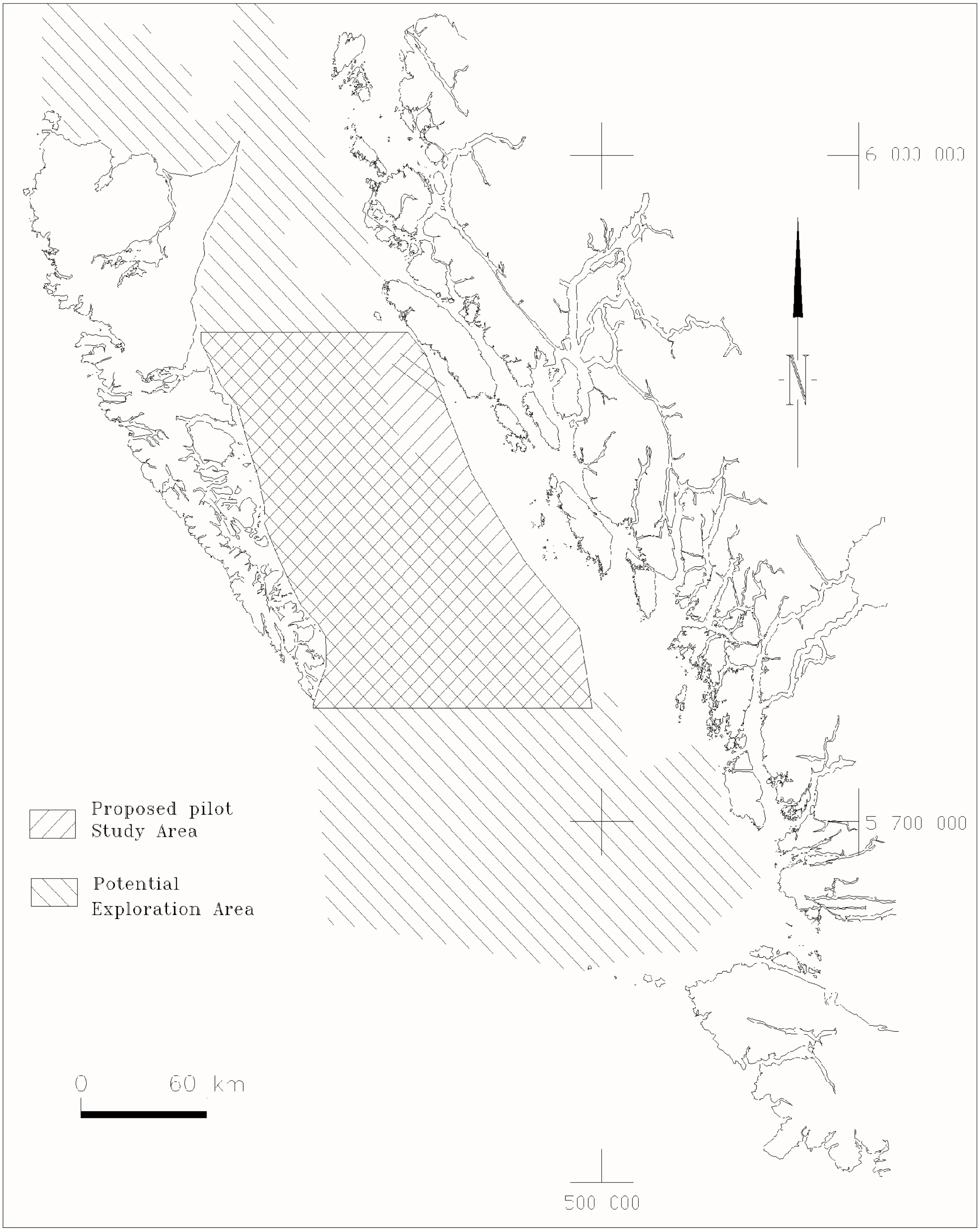

Figure 2.21: *Suggested pilot study area and potential areas of exploration and drilling activities as indicated by geological conditions (Source: Hannigan et al, 1998)*

Industry practice has been to focus initially on oil potential within offshore basins since oil is economically more valuable. Exploration within an area usually progresses from drilling large structural traps, to drilling subtle and smaller structural traps to eventually drilling stratigraphic traps. We therefore expect industry to focus their attention on large structures in areas where they estimate the oil potential to be the highest. Industry will most likely focus initially in the southern half of Hecate Strait approximately from the Sockeye B-10 well (Well 13 in Fig. 1.3) south into Queen Charlotte Sound. This covers the basal sand within the Haida Formation and the region where tertiary source rocks are expected to be marine shales (more oil prone). This is also where oil shows and gas kicks were observed in wells, for example the Sockeye B-10 well.

This above description covers a large portion of the Hecate and Queen Charlotte Basins and is too large for a pilot study. Figure 2.21 outlines a smaller area encompassing part of Hecate Strait from southern Graham Island to southern Moresby Island and east-west from the Queen Charlotte Islands to the Mainland. The data bases in this area are widely spaced but are sufficient to provide a first pass look at geohazards on a regional scale.

o Relevance to socio-economic impact

The pilot area outlined in Fig. 2.21 covers an important fishing region for ground fish, herring, shrimp, prawns and salmon. Moreover it encompasses several important population centres within the region, a number of First Nations reserves, at least one park and several proposed protected areas and ecological reserves.

3.0 Existing data bases and references for the seabed and shallow subsurface

3.1 Data bases

This section provides a snapshot of the different types of marine survey data available within the Queen Charlotte region. It focusses on data that is useful for mapping the seabed and shallow subsurface. However some of the potential field (geophysical) survey techniques (gravity and magnetics) and deeper seismic survey data useful for petroleum exploration have been included. This is not an exhaustive list of available data but it does show the approximate extent of the existing data.

o Navigation

Navigation is an essential component of any marine survey by providing accurate vessel survey track plots for locating all data collected. It provides the coordinates for plotting the data and for relocation. For data collected by the Geological Survey of Canada the navigational data are stored at the Pacific Geoscience Centre in Sidney, British Columbia. Industry navigational data are stored with the petroleum exploration companies, although paper copies of track plots for data collected during petroleum exploration are stored with the National Energy Board in Calgary.

o Bathymetry

Bathymetry provides a map of the seafloor topography and as such is basic to any seafloor investigation. Bathymetric data are available from The Canadian Hydrographic Service as published charts and field sheet products. Sources of digitized bathymetric data are also commercially available (e.g. through Nautical Data International, Inc.).

o Tides and Currents

The Canadian Hydrographic Service is also the custodian for data on tides and currents in the Queen Charlotte area.

o Sidescan sonar

All the sidescan data available in the Queen Charlotte region has been collected by the Geological Survey of Canada (Pacific Geoscience Centre). Figures 3.1 and 3.2 are index maps showing the locations of most available seismic and sidescan data in the Queen Charlotte region.

o Multibeam

Multibeam is a relatively new technique and there have only been a few small surveys conducted along the West Coast. The surveys in the Queen Charlotte region have been conducted by the Geological Survey of Canada under contract to Parks Canada. These are very detailed, near-shore surveys for marine archeological studies. The Geological Survey of Canada at the Pacific Geoscience Centre and the Atlantic Geoscience Centre in Dartmouth, Nova Scotia have these data.

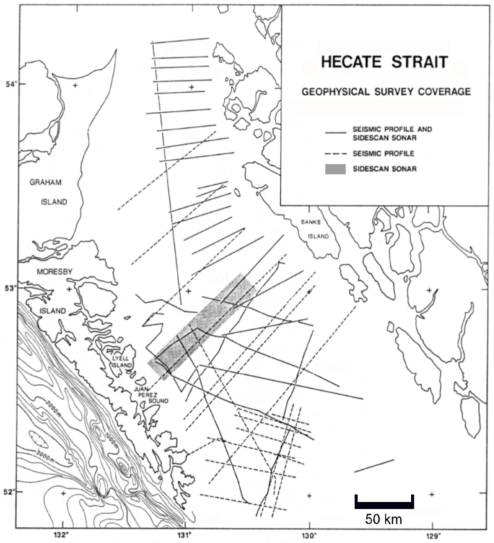

Figure 3.1 *Shallow high resolution seismic and sidescan sonar data collected in the Hecate Strait during 1981 to 1988 (from Barrie and Bornhold, 1989).*

o Shallow seismic

Shallow seismic data have been collected in Hecate Strait (Figs. 3.1 and 3.2), Queen Charlotte Sound and Dixon Entrance by the Pacific Geoscience Centre (PGC). Shell Canada Resources Limited collected shallow sparker data in the 1960's which is available through the National Energy Board (NEB) in Calgary, Alberta. The sparker data is on microfiche or available as paper copies since the digital data, if it exists, still belongs to Shell. Chevron may have collected shallow seismic data in the Queen Charlotte region but further research at NEB would be required to check on it.

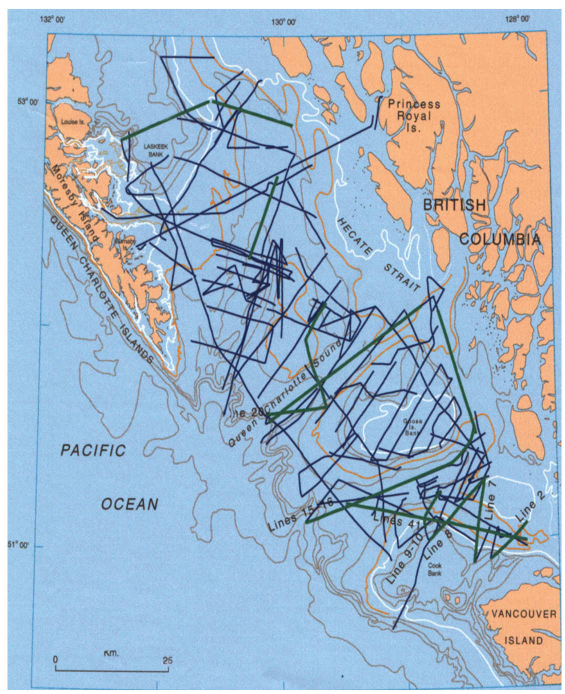

Figure 3.2: *Shallow high resolution seismic and sidescan sonar data collected in Hecate Strait and Queen Charlotte Sound during 1992 (from Josenhans, 1994).*

o Borehole and seafloor samples

Figure 3.3 is a map of the Queen Charlotte region showing some of the available sediment core and surficial (grab) sample data collected by the Geological Survey of Canada (Pacific Geoscience Centre). Most of these data are stored at PGC. Shell Canada Resources Limited collected seafloor samples in the 1960's. The NEB has maps showing the location of these samples. The actual samples are still retained by Shell.

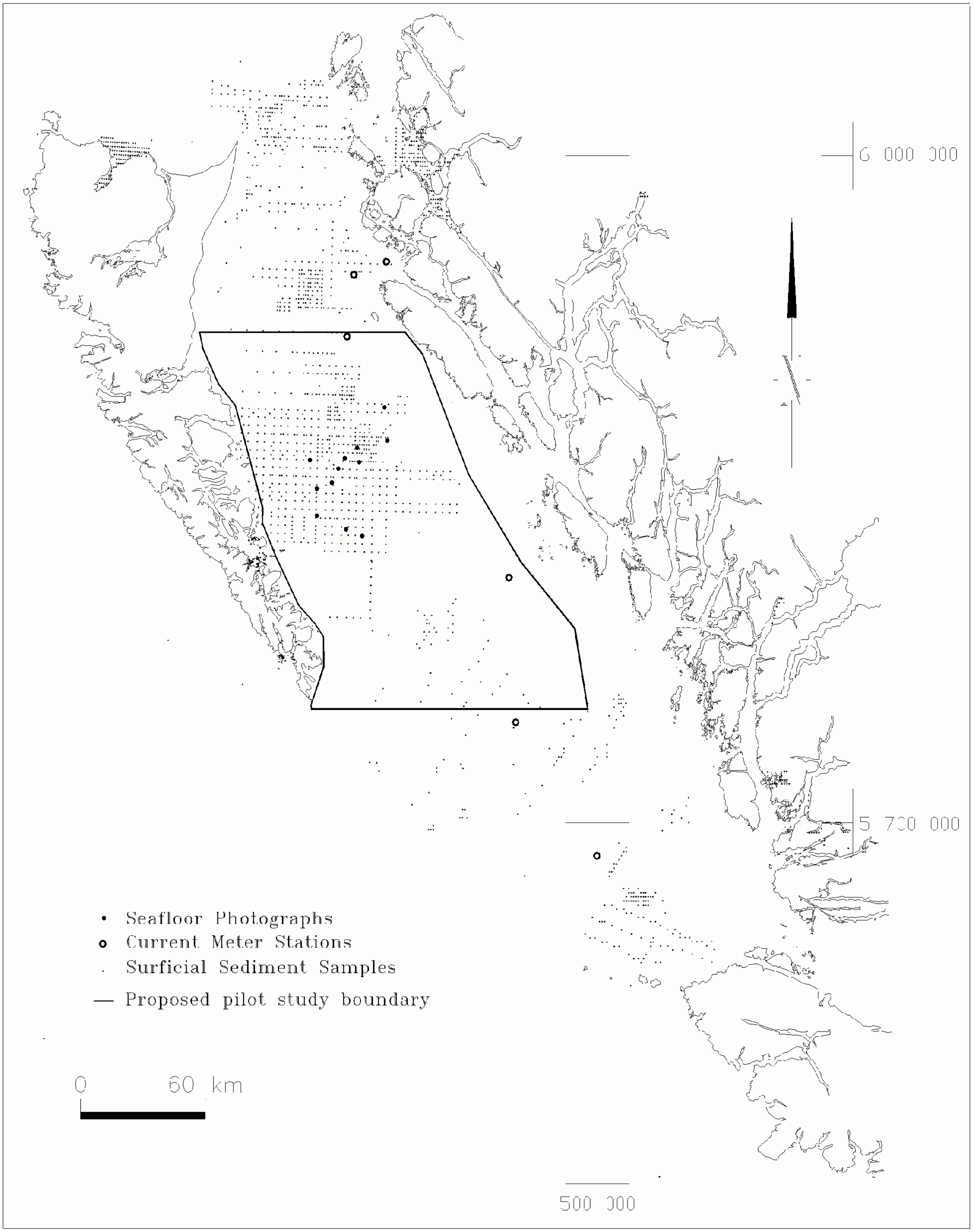

Figure 3.3: *Distribution of bottom sediment sample locations, recording current meter stations and seafloor photography (Barrie and Bornhold, 1989).*

o Potential field

The Geological Survey of Canada has flown airborne magnetometer surveys and collected regional gravity data in the Queen Charlotte area. These data are located in Ottawa and can be obtained from the Geological Survey of Canada Chevron Canada Resources Limited and perhaps Shell Canada Resources Limited have collected airborne magnetometer data in the region. Paper maps of these data are stored at NEB. The original data (analogue or digital) are still retained by industry.

3.2 Data base references

- For sidescan and multibeam data, shallow high resolution seismic data, sediment core and surficial sediment sample data and limited deep reflection and refraction seismic data;

  Pacific Geoscience Centre
  9860 West Saanich Road
  P.O. Box 6000
  Sidney, BC V8L 4B2
  (250) 363-6500

- For hard copy maps and seismic sections, copies of potential field data and well data obtained during petroleum exploration;

  National Energy Board
  444 7^{th} Avenue S.W.
  Calgary, AB T2P 0X8
  (403) 292-4800

- For potential field (gravity and magnetic) survey data;

  Geophysical Data Centre
  Geological Survey of Canada
  615 Booth Street
  Ottawa, ON K1A 0E9
  (613) 995-5326

- For bathymetric, tide and current data;

  Canadian Hydrographic Service
  Department of Fisheries and Oceans
  9860 West Saanich Road
  P.O. Box 6000
  Sidney, BC V8L 4B2
  (250) 363-6369

- For electronic charting and digital bathymetric products;

  Nautical Data International, Inc.
  1 Military Road
  St. John's, NF A1C 2C3
  (709) 576-0634

4.0 Conclusions and Recommendations

o A high interest area for potential offshore exploration is located in southern Hecate Strait and northern Queen Charlotte Sound of British Columbia.

o Technology exists to map and identify any potential seafloor geohazards in the Queen Charlotte region.

o The high interest exploration area is located in important fishing and spawning areas. It also encloses and is surrounded by numerous sensitive areas, including ecological reserves, parks and marine protected areas.

o The data bases for bathymetry, high resolution seismic, sidescan sonar and sediment sample collections in the Queen Charlotte region are not extensive but in the high priority area, the data set density is generally suitable for regional mapping of geohazards.

o Multibeam bathymetry is an effective technique for detailed mapping of potential geohazards however, it has not been utilized in Queen Charlotte region except for a few localized, site-specific studies.

o Offshore industry drilling practices have significantly improved over last 10 years.

o Extensive regulations for offshore hydrocarbon exploration and development exist worldwide and in Canada (for the East Coast and Beaufort Sea).

o It is recommended to carry out a regional desktop mapping study of potential marine geohazards. This study could focus on a high priority area for offshore oil exploration in the region and would make use of existing bathymetric, seismic, sidescan, sediment sampling and other available non-proprietary data. A proposed pilot study area is described in this report.

o It is recommended that further effort be expanded into locating, identifying and cataloguing existing marine data suitable for mapping geohazards. Additionally, in conjunction with Ministry offices, a comprehensive digital (GIS) data base should be created from historical (existing) marine mapping and environmental investigation products. Such a system would likely be based on an existing government in-house GIS system but it's creation would be focused on applications for environmental and seafloor geohazard evaluation related to the offshore oil industry.

o Based on the presentation of results of the desktop study, it is recommended that a detailed bathymetric and marine high resolution geophysical data acquisition program be developed and undertaken in specific priority areas of importance to the British Columbia government. This strategic program would include multibeam bathymetry, sidescan sonar, high resolution seismic and sediment sample collection. The deliverables of such a pro-active program would fulfil a variety of needs and concerns that are highly pertinent to coastal community requirements, environmental and possible aboriginal issues that could arise as a direct consequence of offshore hydrocarbon exploration and development activity.

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