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ECOSYSTEM OVERVIEW:

PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA)

APPENDIX A: GEOLOGY

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1.0 INTRODUCTION

The Pacific Coast as it is seen today is the result of geological processes that have been ongoing for hundreds of millions of years. Over the largest time scale, the dominant process involved is plate tectonics, by which terranes from other parts of the world were accreted onto North America. Much of British Columbia (BC) was added on to North America in this way. The slow but inexorable forces involved in this process also caused the complex tectonic uplift, faulting and buckling of the crust resulting in the formation of the margin parallel mountain ranges of BC. Subsequent erosion of these mountains infilled the sedimentary basins that developed through faulting and subsidence between these ranges.

The tectonic forces that have formed the western Canadian margin continue to this day and BC's offshore is underlain by a complex combination of plate boundaries including a subduction zone, spreading ridges, and transform faults. This results in a variety of earthquake environments frequently generating earthquakes of magnitudes greater than 9 that have occurred roughly once every 300 to 500 years.

Over the last two million years, glaciation has been a dominant factor in the development of BC landscapes, surficial geology and soils. In many areas, subsequent glaciations have largely erased the effects of the previous ones, and as a result, many of the glacial features seen today are a product of the last glacial advance (between 10 and 30 thousand years ago). The terrestrial glacial surface has, in turn, been modified by fluvial erosion and deposition during postglacial time (the last 10,000 years), while marine geomorphology has been shaped by changing sealevels, tides, currents, and littoral processes. Continentally derived sediment input to the continental shelf has been limited since glacial retreat because the deep basins of the coastal fjords and channels allow the settling of river borne sediments. This results in a 'sediment starved' shelf where the older glacial deposits are re-worked in shallow water less than 100 m. This condition has also meant that a relict shelf occurs in deeper water where conditions have remained relatively unchanged, and a coastline dominated by rocky shores with few sand and gravel beaches.

The physical features of the coast also affect the freshwater input to the marine area. PNCIMA contains a variety of watershed forms resulting in different hydrologic profiles, though spring and summer meltwater runoff dominate the mainland watersheds which provide most of the freshwater input. This input and its timing are critical to phytoplankton blooms which form the base of the marine food chain. Global warming is already seen to be affecting the timing and volume of freshwater input in this area.

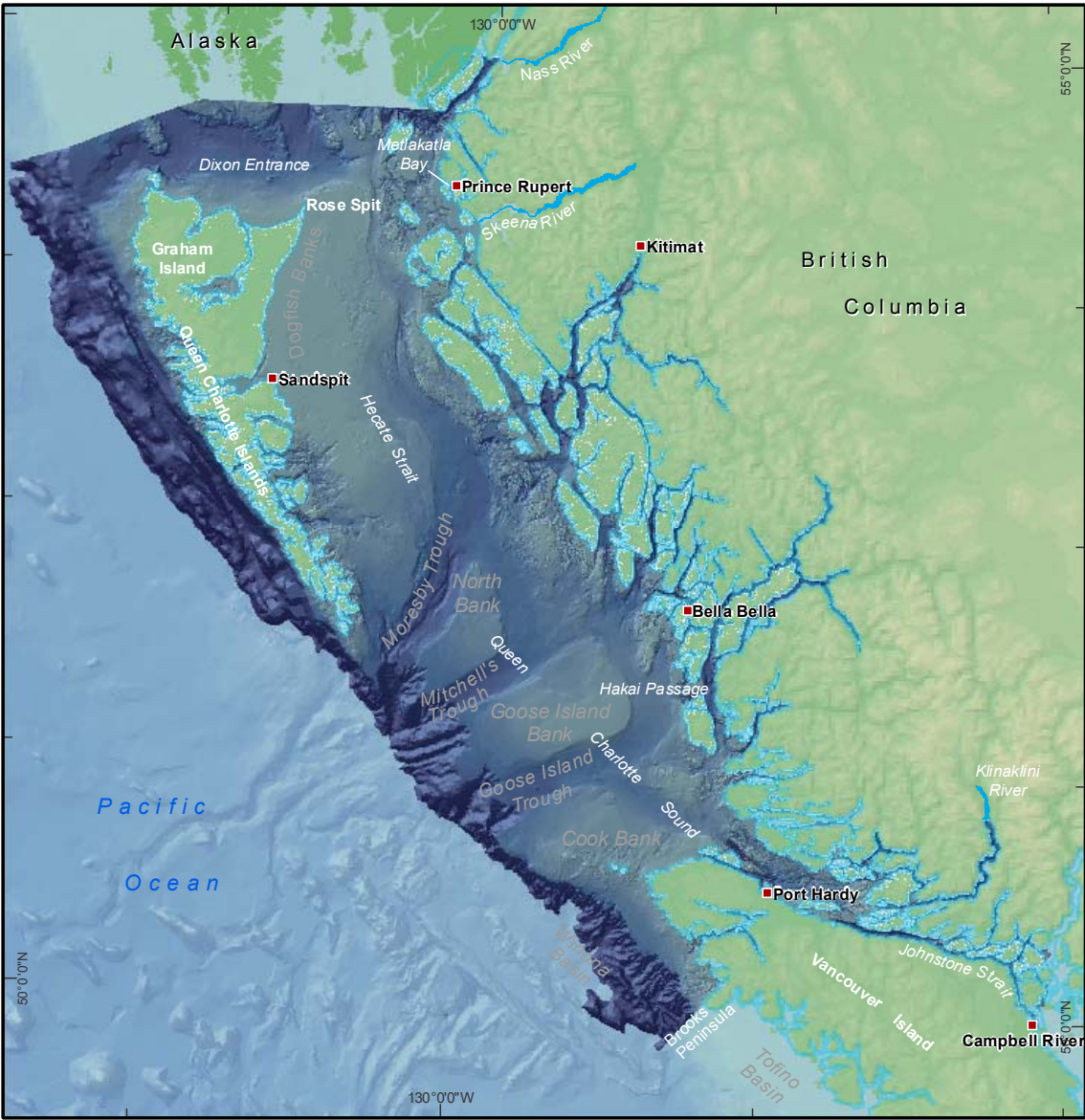
PNCIMA also has a potential to host significant petroleum resources. The Queen Charlotte Basin is one of four sedimentary basins found on Canada's Pacific margin. Explorations from the 1960s to the 1980s suggest that this basin may hold significant

reserves of oil and gas. Natural gas hydrates have also been found on southern portions of BC's continental slope and may also exist on the slope within PNCIMA.

1.1 Key Points

The geological environment forms the underlying habitat of the area and significantly affects the physical functioning of the ecosystem. This includes such features as:

- the steep and rugged coastal mountains and their effect on climate, rainfall and watershed function,
- the valleys and fjords that cut into these mountains resulting in the dominance of estuarine circulation in the nearshore environment and creating a sediment-starved shelf,
- the abundant mainland islands creating many kilometres of protected and semi-protected coastline and waterways,
- the presence of the Queen Charlotte and Vancouver islands (Figure A.0) which give rise to a wide range of wave exposure regimes and affect currents and oceanographic circulation in the area,
- the glacially scoured continental shelf with its cross cutting troughs, intervening banks and the dominance of glacially derived sediments which are likely to be a controlling factor in benthic habitats,
- the presence of the Queen Charlotte Basin beneath the continental shelf, which has the potential to contain significant oil and gas reserves, and the presence of onshore oil seeps and offshore pockmarks and shallow gas fields that are manifestations of hydrocarbons leaking from and through the basin rocks,
- the seismic activity of the area which is prone to a wide range of magnitudes of earthquakes,
- the recently discovered siliceous sponge reefs are globally rare and are suspected of being a critical habitat for a variety of species including rockfish and juvenile fish of various species,
- the coastal sedimentary regime in the shallow western portion of Hecate Strait that has led to rapid coastal retreat along the eastern Graham Island shore and growth of Rose Spit and the northern side of Graham Island.



Legend

- Fisheries and Oceans Canada / Pêches et Océans Canada
- PNCIMA Boundary
- Communities
- Rivers
- Alaska

0 30 60 120 Kilometers

Notes:
 Source Information:
 - BC Altimetry provided by NOAA
 - Pacific North Coast Integrated Management Area Boundary and Offshore Bathymetry provided by DFO.
 - Communities provided by NRCAN
 - Lakes / Rivers provided by BC MOE

Projection: BC Albers, NAD 83
 Production Date: June 18, 2007
 Produced By: OHEB GIS Unit, DFO

Figure A.0 PNCIMA region showing locations and features of BC waters.

1.2 Uncertainties, Limitations, and Variability

Terrestrial bedrock geology is well understood in PNCIMA. Submarine bedrock geology is less well constrained. Current knowledge of seafloor sediments and substrate material is patchy and in most areas limited by the need to extrapolate between widely spaced sampling points and geophysical survey lines. The surficial geology is likely to be a significant factor in determining benthic habitat conditions. Understanding of the role of surficial materials as habitat and how they interact with various biota is critical to understanding benthic ecosystem function.

Multibeam sonar technology is providing high-resolution bathymetric and seabed characterization data, though it will require many years to compile a shelf-wide dataset. Detailed understanding of marine geohazards within the region is limited. Slope stability could represent a significant geohazard as extensive areas of slumped and failed sediments have been described in the PNCIMA region, but much further work is required to provide constraints to the degree of risk associated with this potential hazard. Knowledge of the erosion, transport, and deposition of marine sediments within PNCIMA is generally poor and extensive new research would be required to advance understanding in this area. While the exact timing of large earthquakes cannot be predicted, current understanding allows a high degree of certainty that the subduction zone off of the west coast of Vancouver Island is currently locked and will likely produce an earthquake around magnitude 9 within the next several hundred years. The transform fault off the Queen Charlotte Islands is known to produce greater than magnitude 8 earthquakes, and is the site of Canada's largest recorded earthquake, a magnitude 8.1 event in 1949, but the frequency of these events is unknown. Oil and gas seeps have been encountered onshore and more recently offshore. Study of these submarine gas vent sites has only begun. In view of the moratoria on oil and gas exploration, field research regarding the petroleum resources of the region has languished, with the last multichannel seismic survey undertaken to assess structural controls on basin development being done nearly 20 years ago.

1.3 Major Sources of Information or Data

Geoscience research including onshore and marine mapping, maintenance of GIS databases, and regional survey work is done by the Geological Survey and Development Branch of the provincial Ministry of Energy and Mines and the Pacific division of the Geological Survey of Canada (GSC), a part of the Earth Sciences Sector of Natural Resources Canada. The Pacific Geoscience Centre (GSC office in Sidney) is the base of the marine geology and earthquake seismology expertise in this region.

1.3.1 Multibeam Surveys

The Canadian Hydrographic Service of Fisheries and Oceans Canada (DFO) in association with the GSC are undertaking extensive and detailed multibeam sonar surveys of the continental shelf and upper slope. The vessels employed in this program include the *CCGS Vector* and the motor launch *Otter Bay*. The vessels are utilized in different depth ranges for the multibeam survey work as a consequence of the type of equipment mounted, with *Otter Bay* normally surveying from 5 – 150 m water depth while the *Vector* typically surveys deeper than 80 m and resolution is limited to waters less than 800 m depth. The deeper portion of PNCIMA will thus require a different vessel or multibeam system for deep-water surveys on much of the slope. Apart from the bathymetric data, backscatter or seabed reflectivity data are collected simultaneously that provides information about the character and potentially the texture of the seabed. In addition, recent research is being devoted to analyzing the properties of the water column reflections that occur in a swathed area with the objective of describing biotic or oceanographic phenomena in the water column. This ongoing work will provide highly detailed digital datasets and maps of seafloor topography and the backscatter data will facilitate the mapping of the surficial geology including seafloor sediment texture.

Useful publications summarizing geologic information for this area include:

- Two major summary books for the area are:
 - Geology of the Cordilleran Orogen in Canada (Gabielse and Yorath *eds.* 1991); and
 - Quaternary Geology of Canada and Greenland (Fulton *eds.* 1989).
- Two excellent books for the general public are:
 - Geology of British Columbia: A Journey Through Time (Cannings and Cannings 1999); and
 - Where Terranes Collide (Yorath 1990).
- Numerous reports on Offshore Oil and Gas have been produced and generally provide excellent summaries of a number of topics including the geology of the area. These reports include:
 - Offshore Queen Charlotte Islands Initial Environmental Evaluation Volumes 1-3 (Petro-Canada 1983);
 - Initial Environmental Evaluation for Renewed Petroleum Exploration in Hecate Strait and Queen Charlotte Sound Volumes 1 & 2 (Chevron Canada Resources Ltd. 1982);
 - British Columbia Offshore Oil and Gas Technology Update (Jacques Whitford Environment Limited 2001);
 - British Columbia Offshore Hydrocarbon Development: Report of the Scientific Review Panel (Strong *et al.* 2002);

- Physical Oceanographic and Geological Setting of a Possible Offshore Oil and Gas Industry in the Queen Charlotte Basin (Cretney *et al.* 2002a);
- A Review of the State of Knowledge of Marine and Shoreline Areas in the Queen Charlotte Basin (LGL Limited 2004);
- Report of the Expert Panel on Science Issues Related to Oil and Gas Activities, Offshore British Columbia (Hall *et al.* 2004).
- Other books and reports containing geological information include:
 - The Outer Shores (Scudder and Gessler *eds.* 1989);
 - The Gulf of Alaska: Physical Environment and Biological Resources (Hood and Zimmerman *eds.* 1986);
 - Biophysical Evaluation of the Central Coast of BC with Special Reference to Aquaculture (Ricker and McDonald 1995);
 - Biophysical Suitability of the North Coast and Queen Charlotte Islands Regions of BC for Salmonid Farming in Net Cages (Ricker and McDonald 1992).

1.4 Data Gaps and Lack of Knowledge

Specific recommendations of the expert panel on science issues to the Royal Society of Canada included swath multibeam mapping (Hall *et al.* 2004), and this gap is being addressed. Multibeam imagery will eventually provide a very detailed base for the complete understanding of the regional seabed surficial geology and seafloor physical environment. The continental shelf will require many (estimated >8) years of surveying at the present rate of data acquisition and the inshore areas of the PNCIMA region will require many additional years of surveying as shallow water ways, channels and shoals are completed. The deeper portion of PNCIMA will require different multibeam technology to be applied to acquire data in water depths greater than 800 m. Other data related to shelf sediments and sedimentology gathered in the inner shelf area of PNCIMA is sparse. Very few studies of the inner shelf seabed geology, inshore geo-environmental processes and the linkages between the open shelf and nearshore areas have been done. Very few geoscience data sets of any type exist for the continental slope of PNCIMA. This portion of PNCIMA represents a significant challenge to survey capacity, given the lack of a suitable multibeam system. Thus the central portion of PNCIMA is well studied in comparison to either the inshore eastern or deep-water western part of the study area.

2.0 BEDROCK GEOLOGY

2.1 Makeup and Origin of BC Coastal Bedrock

A detailed summary of British Columbia bedrock geology and tectonic history can be found in Gabrielse and Yorath (1991), particularly Chapter 2 Gabrielse *et al.* (1991) as well as Clague (1989). The following is a summary of the material relevant to this overview.

The level of detail of our current knowledge of BC geology is revealed in the complexity of Figure A.1. This map and Figure A.2 (the same data grouped into simple rock types), reveal a longitudinal northwest trending pattern to the geological makeup of BC. This pattern has been divided into 5 longitudinal belts based on lithology, structural style and morphology (Sutherland Brown *et al.* 1970; Wheeler and Gabrielse 1972 as cited in Gabrielse *et al.* 1991). An increasing understanding of plate tectonic implications of the regional geology of BC was contributed by Monger *et al.* (1972 as cited in Gabrielse *et al.* 1991). In particular it became clear that the physiography and bedrock geology of BC is a result of large-scale tectonic events that have given rise to these distinct longitudinal belts.

In the early 1980s the mapped lithostratigraphic units were categorized according to the setting in which they formed (Tipper *et al.* 1981), resulting in the detailed tectonic assemblage map of Figure A.1. At the same time, information became available that suggested large portions of BC bedrock did not form next to the bedrock they are now found in contact with (Coney *et al.* 1980). This led to the concept of “terrane”, which are large pieces of the Earth’s crust that have been moved by plate tectonics to their current position. These plates are believed to have broken up and been smashed together many times over the geological history of the Earth. Much of BC is formed from terranes that have been accreted to (piled and smeared up against) the North American continent (Figure A.3). This process has produced that longitudinal appearance of the geological units. The main terranes making up PNCIMA are the Alexander and Wrangellia Terranes, which are believed to have joined together prior to joining on to BC (forming the Insular Superterrane).

The coastal portion of PNCIMA includes the Insular Belt (Vancouver and Queen Charlotte islands and much of the continental shelf) and the Coast Belt which is made up of the mainland’s rugged coastal mountain belt. Also, portions of the Intermontane Belt fall within the easternmost edges of the mainland watersheds (Figure A.2). Below is a description of the basic geology of four belts from east to west (summarized from Clague 1989; Gabrielse *et al.* 1991 and http://gsc.nrcan.gc.ca/cordgeo/index_e.php). To illustrate the geologic times listed in the discussion below, refer to Table A.0.

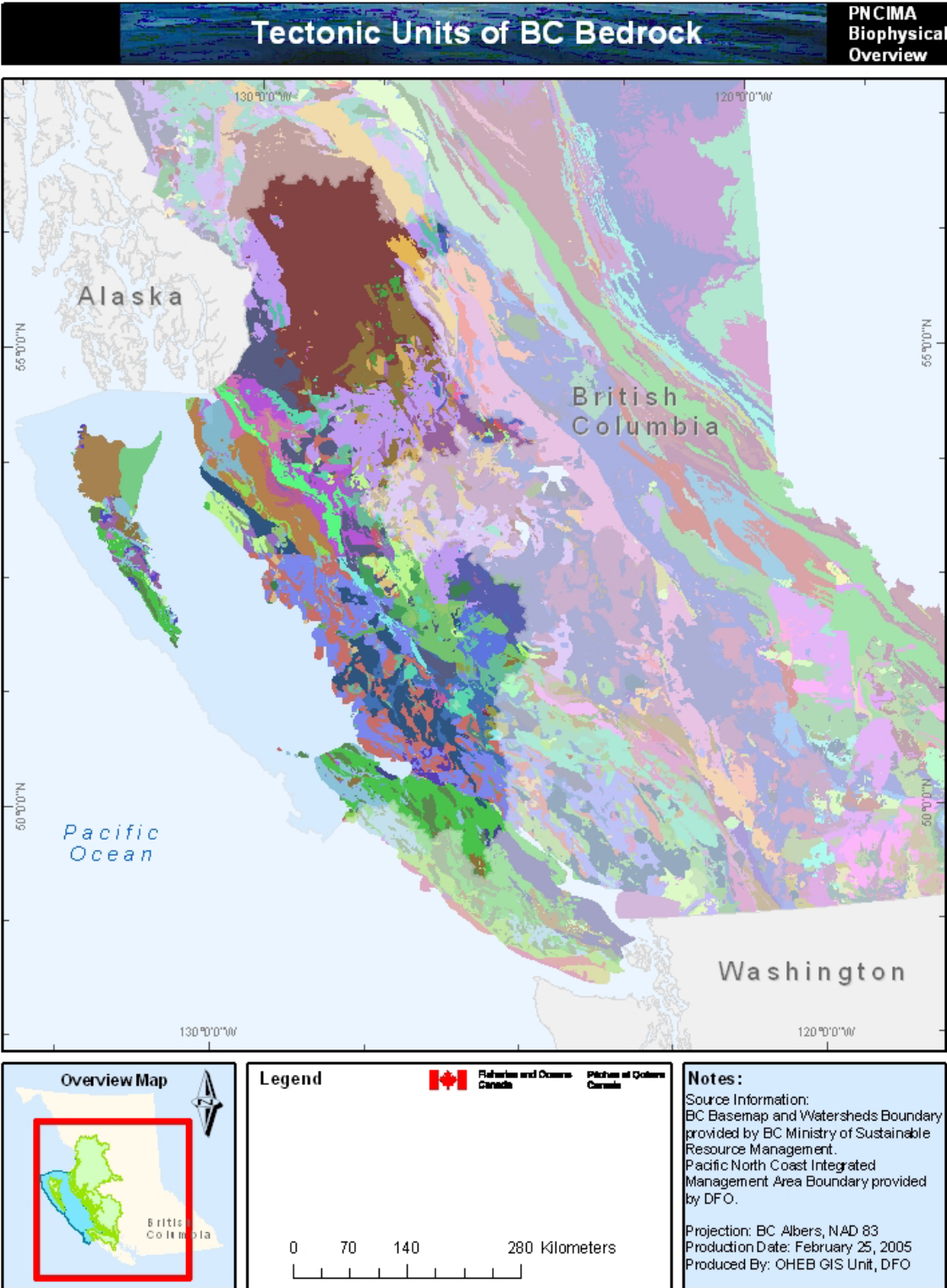


Figure A.1 Tectonic assemblage map compiled to be accurate at a scale of 1:250 000 (data from the BC Ministry of Energy and Mines 2005).

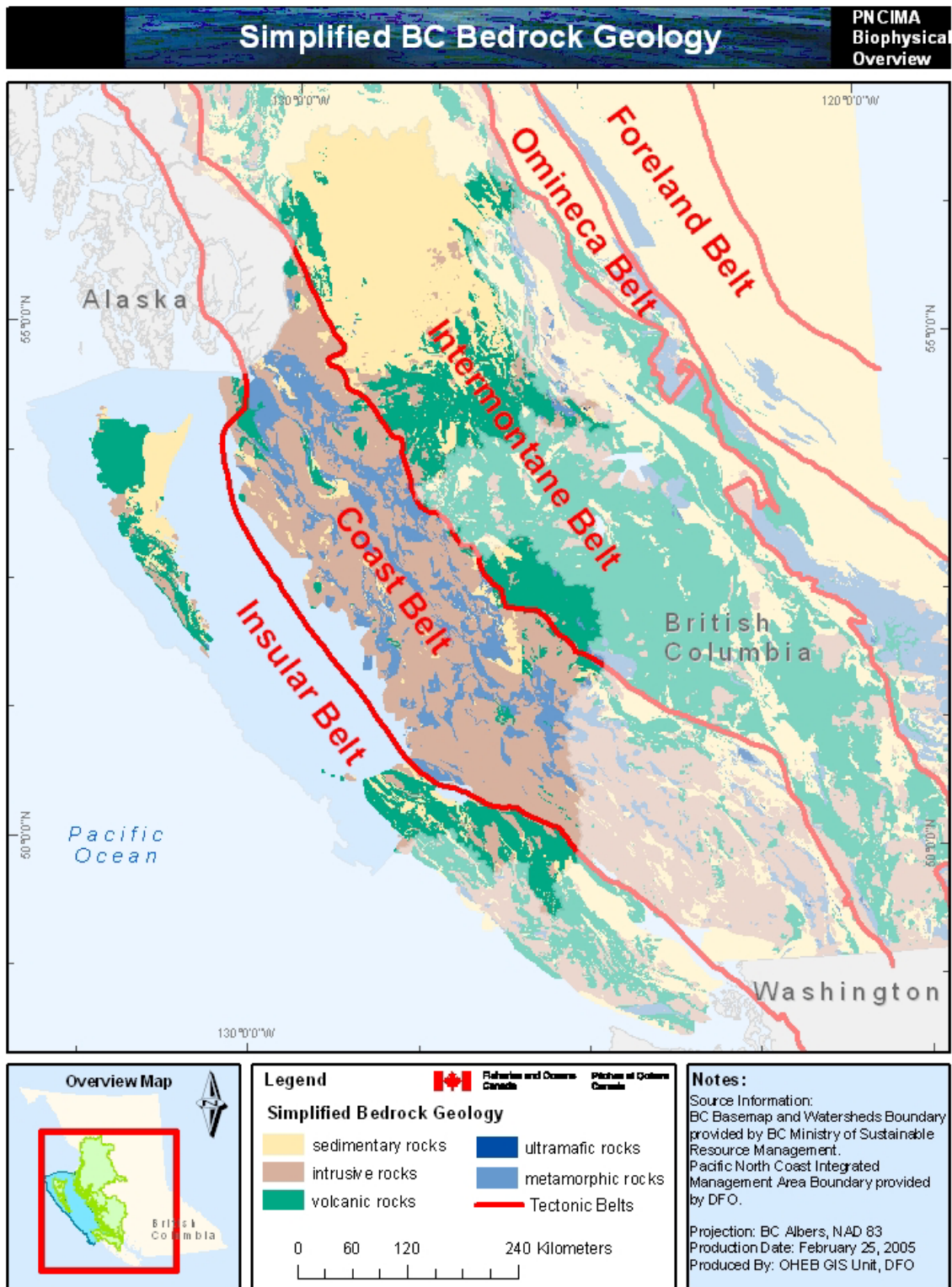


Figure A.2 Bedrock geology simplified into basic rock types with tectonic belt boundaries superimposed (data from BC Ministry of Energy and Mines, updated 2005).

The **Intermontane Belt**, is a low relief, high elevation area made up of high plateaus and rolling uplands situated between two mountainous belts (Coast and Omineca). The belt is made up of three major exotic terranes (Figure A.3) dominantly made up of marine volcanic and sedimentary rocks of Devonian to Jurassic age, which formed before the terranes amalgamated (by the middle Jurassic) and subsequently docked with North America. These rocks are overlain by Jurassic and Cretaceous clastic wedges and flat lying Tertiary volcanic and sedimentary rocks which were laid down during and after accretion of the terrane. These latter two rock types dominate the geologic map (Figure A.2) as they are the rocks most commonly found exposed at the surface.

The **Coast Belt** is dominated by granitic and metamorphic rocks. The belt likely formed as a result of long-term subduction, and the accretion, and form a suture zone (roughly the glue) between terranes. Heat and pressure associated with this subduction caused the metamorphism of existing sedimentary and volcanic strata. The Coast Belt is made up of roughly 80% granitic intrusions (Figure A.2) and forms one of the largest granitic masses in the world generally called the 'Coast Plutonic Complex'. The granites are formed deep in the earth, likely as the roots of volcanoes, and were uplifted and exposed by tectonism and erosion in Cenozoic time, giving BC's mainland coast its distinctively steep and rugged topography. These granitic and metamorphic rocks are dominantly Jurassic to Tertiary in age and overly volcanic and sedimentary rocks dating back to the middle Paleozoic (Figure A.2).

The **Insular Belt** includes the rocks of the Queen Charlotte and Vancouver islands and the submerged bedrock of the continental shelf out to the toe of the slope (PNCIMA's western boundary). The Insular Belt is similar to the Intermontane Belt in that it is a composite of terranes and is dominated by volcanic and sedimentary rocks that formed in marine volcanic arcs and basins ranging in age from the Upper Cambrian to the Tertiary. The terranes probably amalgamated in Middle Jurassic time and collided with the Intermontane Belt during the Cretaceous. Sub-marine portions of this belt are dominated by thick sedimentary successions and volcanics of Tertiary age (see section 1.2 and Figure A.2).

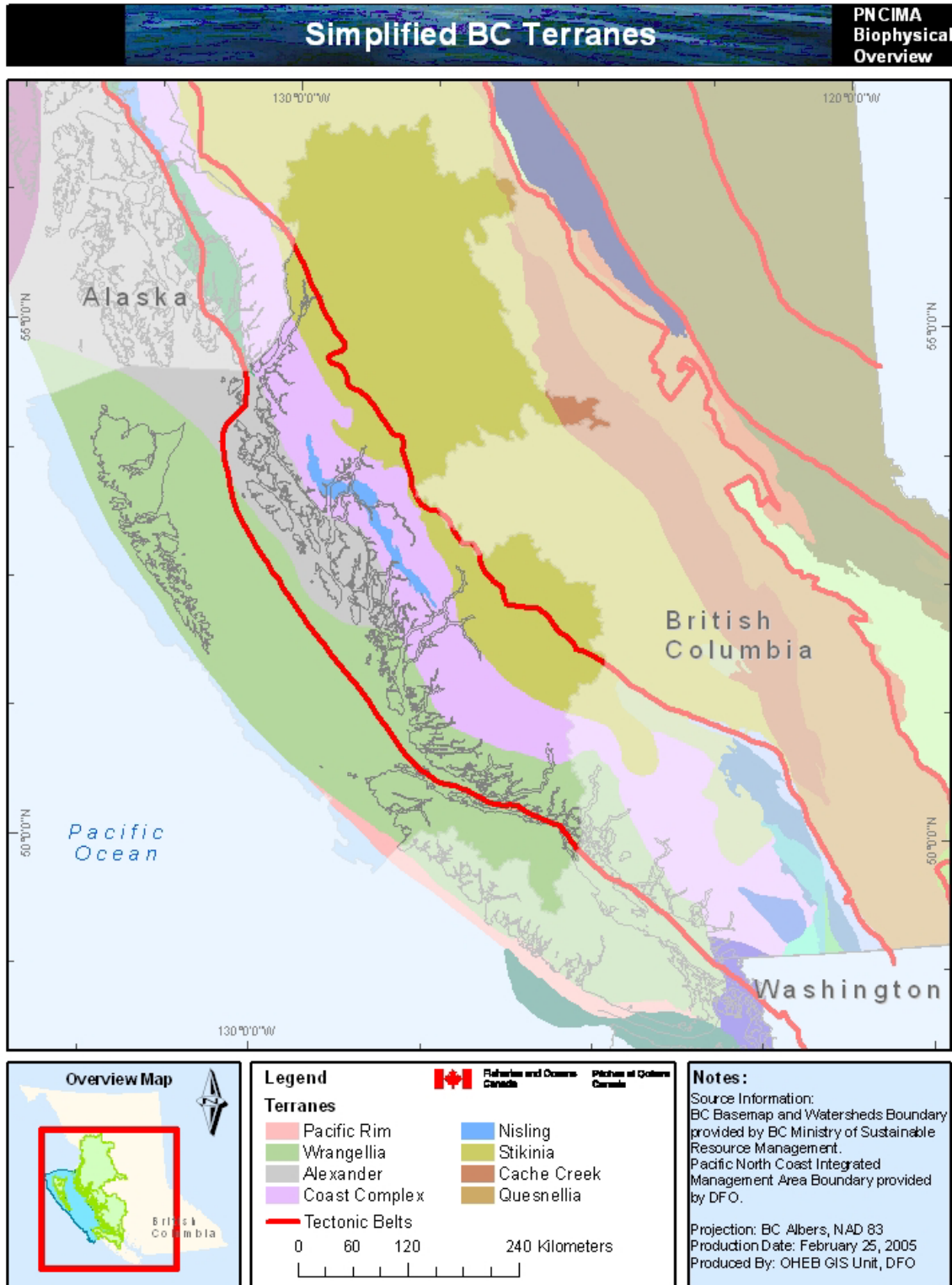


Figure A.3 Simplified terranes of BC (data from the BC Ministry of Energy and Mines).

2.2 Plates, Faults, and Seismicity

Seaward of BC's continental margin there is a highly complex plate boundary produced by the meeting of tectonic plates moving in different directions (Figure A.4). Here, the meeting of the very large North American and Pacific plates with the Explorer plate (a very small remnant of a plate just north of the Juan de Fuca plate) results in a complex morphology. The meeting point of the three plates is called a triple junction, which accommodates the different plate movements in a complex combination of transform faults, spreading ridges, and a subduction zone. South of this triple junction is the subduction zone resulting from the Juan de Fuca and the Explorer plates (dense oceanic crust) sliding beneath the North American plate (less dense continental crust). North of the triple junction is a transform or strike-slip fault known as the Queen Charlotte Fault Zone and which is similar in nature to the San Andreas Fault in that the two plates here are sliding past one another.

Each of these three zones produces slightly differing earthquake environments that contribute to the offshore seismic hazard in this region (Figures A.5-A.7). The world's largest earthquakes occur in subduction zones. When the oceanic crust being subducted is very young and hot, the subduction zones become locked for long periods of time and produce only very large earthquakes rather than a continuous size range of earthquakes.

The Cascadia subduction zone along the coast of southwestern BC and western USA is of this type and produces 'giant megathrust earthquakes' (magnitude greater than 8) (Hyndman *et al.* 1999) at intervals of several centuries. Paleoseismic evidence suggests that such giant earthquakes have occurred here many times in the past, and the most recent one was about 300 years ago (Figure A.5, black circle). The subducting Juan de Fuca plate is currently locked with the North American plate along its entire length from BC to California (Hyndman *et al.* 1999). There is abundant lower magnitude seismicity also found in the region of subduction plates (Figure A.7), however, this seismicity is the result of failure along smaller faults within either the overlying continental crust or the underlying ocean plate. This occurs as a result of the deformation of the plates as their overall movement continues despite the subduction fault being locked. Transform faults like the Queen Charlotte Fault Zone and the famous San Andreas Fault, mark the boundaries where tectonic plates slide past one another. This is expressed as a zone of deformation and seismicity where mechanisms for earthquakes and observed relative motions along any fault strand may be complex. The two sides of the fault become locked together at various places along the fault. As the plates continue to move, the locked areas accumulate stress until they fail, releasing the stress as an earthquake. Transform faults are associated with some of the most seismically active areas in the world. They produce a range of earthquakes from very frequent low magnitude events to larger, potentially damaging events, normally in a complex zone surrounding the transform margin (magnitude 6-8, Figures A.5-A.7). As the earthquakes get larger, the frequency of occurrence decreases at a predictable rate.

In the area of the triple junction itself, the complexity of the junction gives rise to a great many small faults. The result of this and the stresses placed upon this region in accommodating the movements of the three plates, is that seismic activity is very high,

but individual events are rarely of high magnitude. The occasional magnitude 7 earthquakes tend to be the strongest recorded in this area (Figures A.5-A.7).

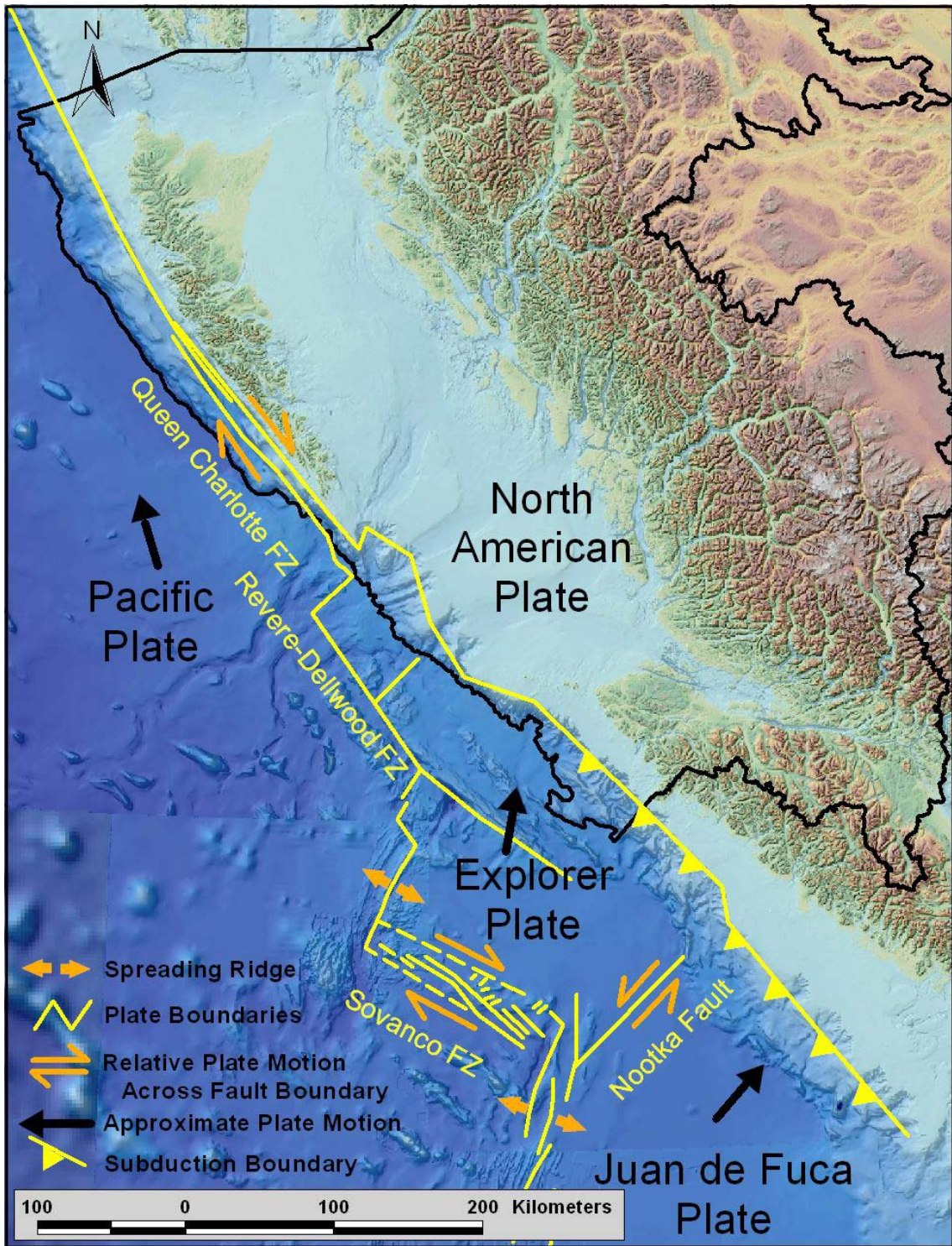
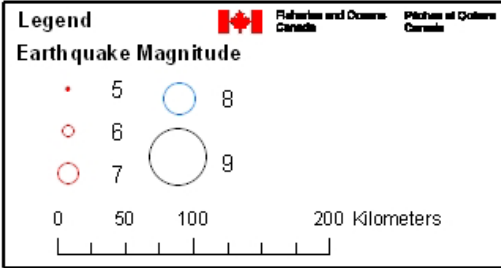
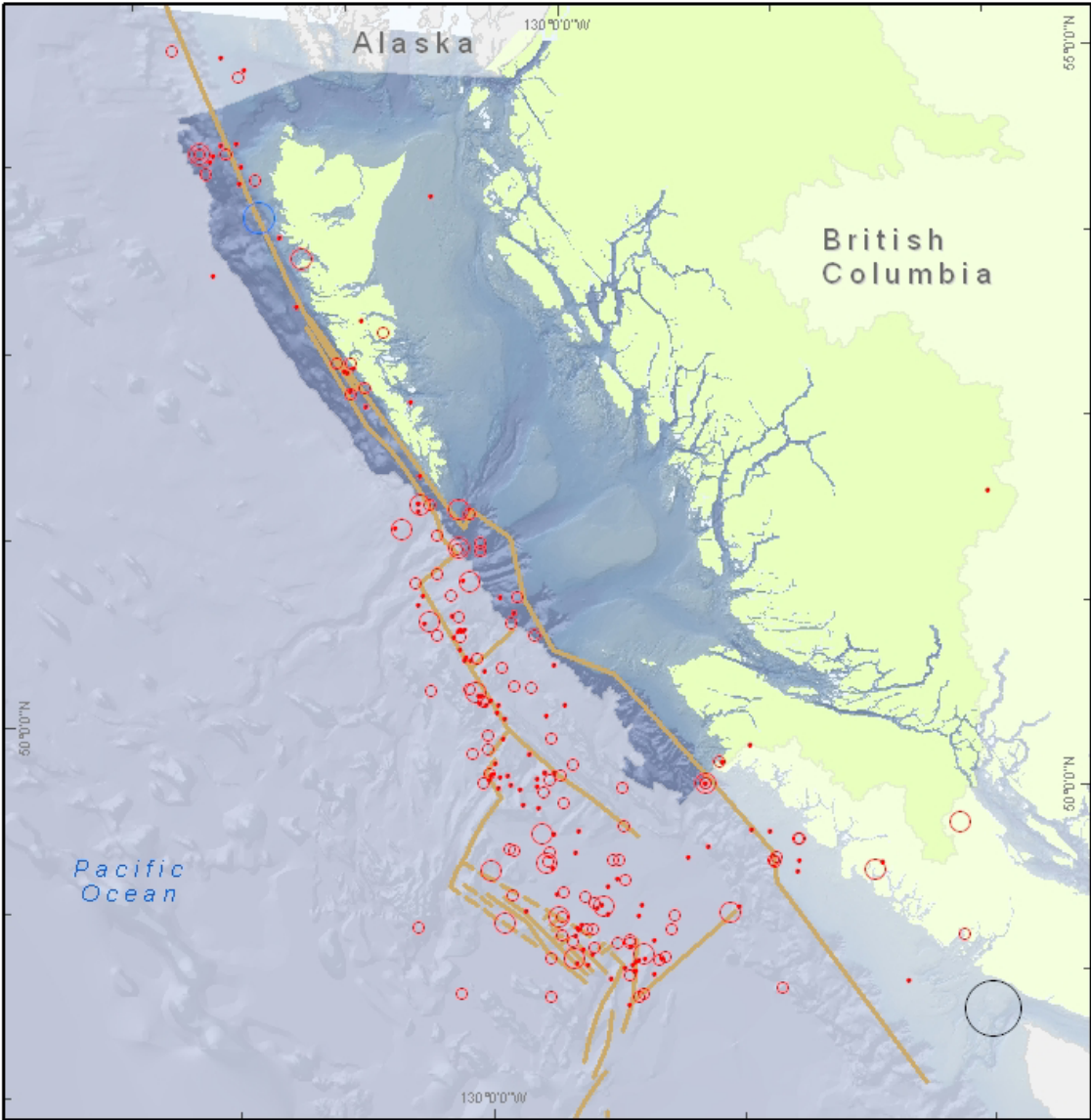


Figure A.4 Plate boundaries and relative plate motion off the coast of BC (data from Natural Resources Canada).

Earthquakes over Magnitude 5 (1700 - 2004) PNCIMA Biophysical Overview



Notes:

Source Information:
 BC Basemap and Watersheds Boundary provided by BC Ministry of Sustainable Resource Management.
 Pacific North Coast Integrated Management Area Boundary provided by DFO.

Projection: BC Albers, NAD 83
 Production Date: February 25, 2005
 Produced By: OHEB GIS Unit, DFO

Figure A.5 All recorded earthquake events along the BC coast of magnitude 5 or greater (data from the Natural Resources Canada, Pacific Geoscience Centre).

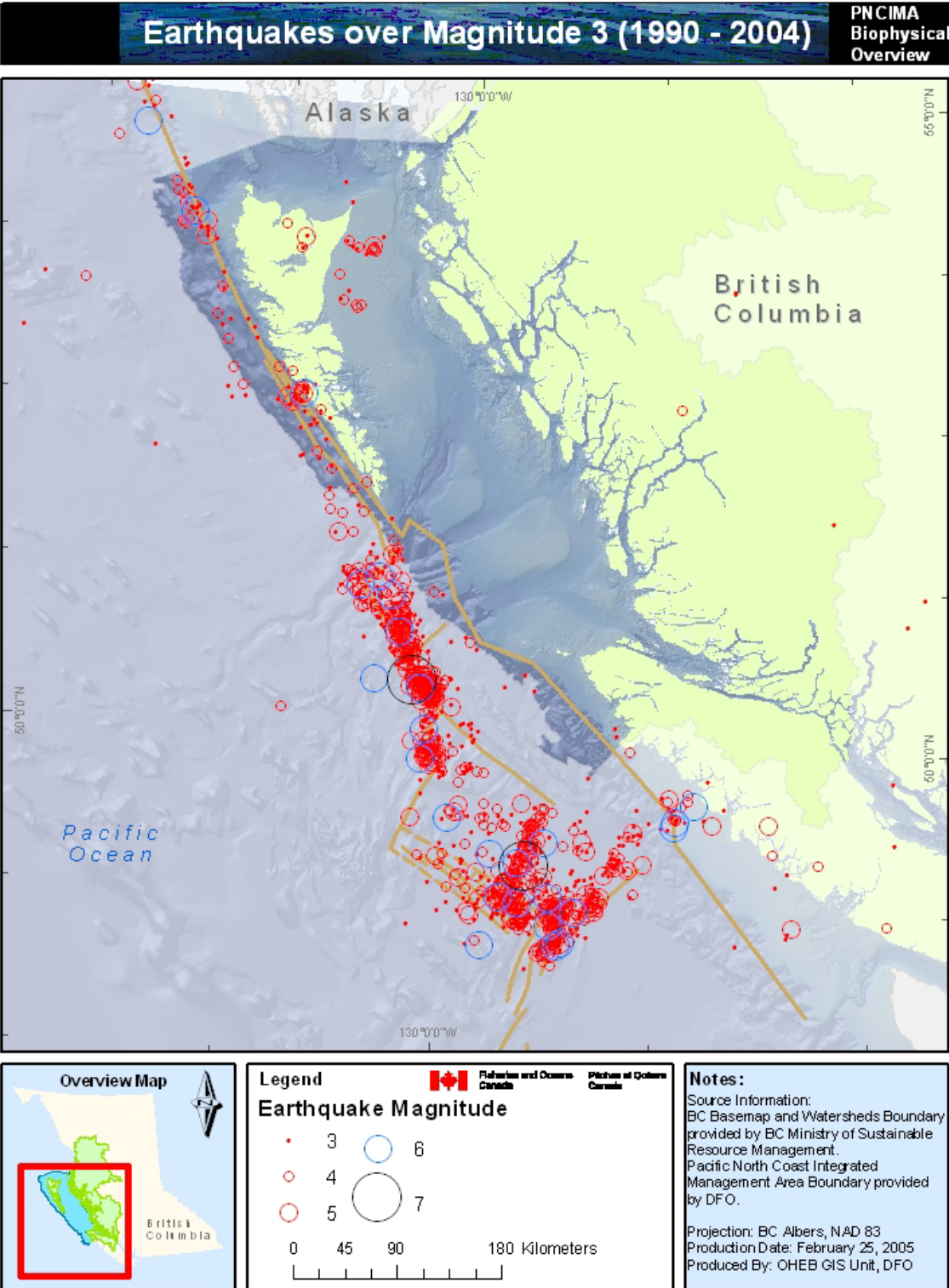


Figure A.6 15 years (1990-2004) of recorded earthquake events along the BC coast of magnitude 3 or greater (data from the Natural Resources Canada, Pacific Geoscience Centre 2005).

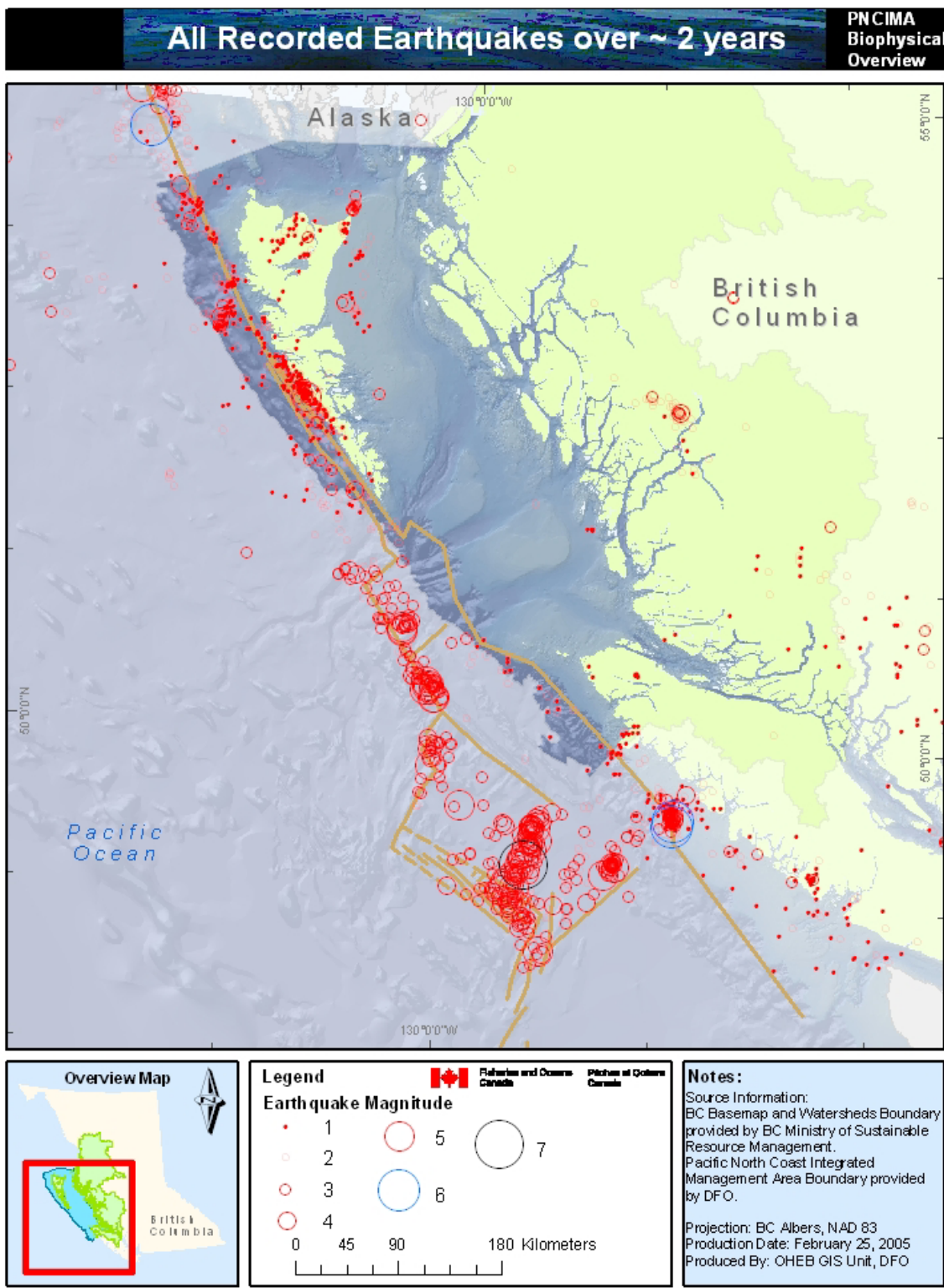


Figure A.7 23 months (Jan 2003-Nov 2004) of recorded earthquake events along the BC coast of magnitude 1 or greater (data from the Natural Resources Canada, Pacific Geoscience Centre).

3.0 GEOMORPHOLOGY

3.1 Quaternary Glaciation

The Quaternary Period is the most recent geological period, dating from approximately 2.4 million years ago to the present. The geological processes that took place in this period sculpted the landscapes whose basic forms were produced by the tectonic events described in section 2.2. Since each glaciation tended to remove or re-work features created by the previous one, most existing glacial features are the result of the most recent glaciation, the Wisconsinan. British Columbia differs somewhat from central and eastern North America in that glaciation consisted of the growth and amalgamation of numerous piedmont glaciers of the Cordilleran Ice Sheet. The local timing of growth and decay differs slightly from that of the Laurentian Ice Sheet due to differences in the climatic influences west of the Rocky Mountains.

The most recent glacial advance is locally referred to as the Fraser Glaciation. During this time period the pronounced glacial geomorphology and surficial materials distribution found throughout British Columbia were developed. This glacial geomorphic heritage includes diverse submarine features directly related to the extensive Fraser Glaciation. Figure A.8 illustrates the current understanding of the maximum extent of the late Wisconsinan (Fraser) glaciation, which is thought to have reached this maximum sometime after 21,000 yr BP (years before present) (Blaise *et al.* 1990) and before the initiation of rapid retreat ~ 15,000 yr BP (Barrie and Conway 2002).

The submarine troughs on the continental shelf in Queen Charlotte Basin are thought to have been filled by piedmont lobes of this glaciation (Josenhans *et al.* 1995), possibly extending to the shelf break although the extent is uncertain for Moresby Trough. Lobate ice masses develop where ice from steep terrain flows out onto a low gradient landscape or plain. Evidence also suggests that the southern portion of the Queen Charlotte Islands and the tip of Brooks Peninsula may have remained ice-free thus providing refugia for plant and animal species that would not have survived a more complete ice coverage. Recently research has focussed on the distribution of ice free land, the organisms there and the timing of glacial events (Hetherington 2002; Josenhans *et al.* 1995; 1997).

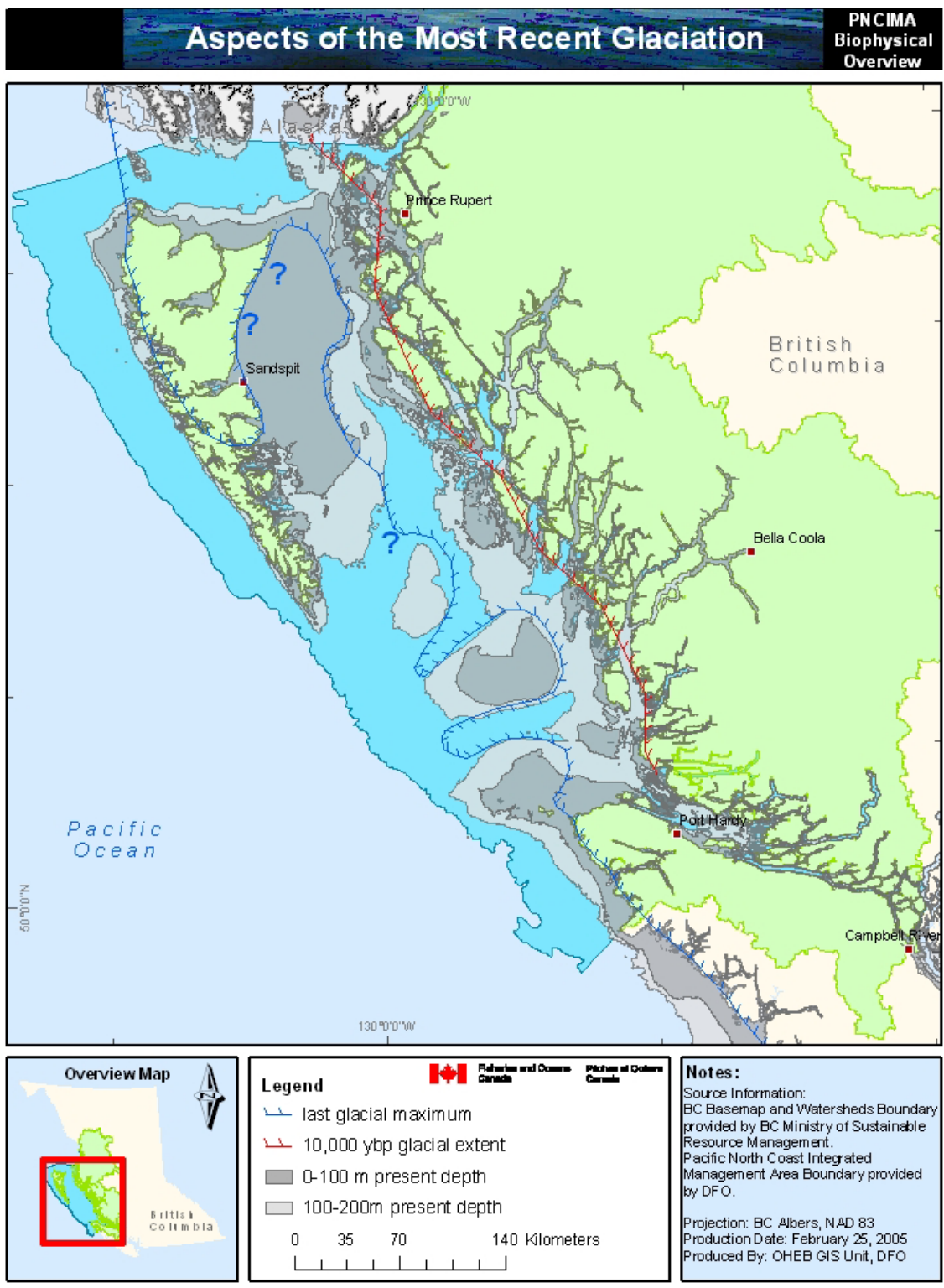


Figure A.8 Map of the approximate location of the last glacial maximum (modified from Blaise *et al.* 1990; Josenhans *et al.* 1995) and the extent of glaciation during retreat at approximately 10,000 year before present (based on Josenhans *et al.* 1995). Question marks denote poor constraint of glacial maximum.

The paleo-oceanography of the PNCIMA region has been studied through the examination of sediment cores and relating the contained microfossil assemblages to oceanographic conditions on the shelf. Oceanographic and tidal currents and therefore water circulation on the shelf would have changed markedly during the physiographic and climate changes that drove and accompanied the sea level changes described below. Examination of this microfossil record indicates that by 10,000 years before present shelf bottom water temperatures were similar to today (Guilbault *et al.* 1997). Details of the oceanographic changes that accompanied deglaciation of the shelf have been illuminated (Guilbault *et al.* 1997) including events such as the Younger Dryas, a rapid cooling event at the end of the Fraser glaciation (Patterson *et al.* 1995). A large-scale outburst flood event that occurred during the deglaciation of the southern BC hinterland in the Fraser River watershed when an ice dam or dams was breached has been observed in cores (Conway *et al.* 1991). This event affected all the waters of the Georgia Basin and would therefore have affected the southern portion of PNCIMA. Details of oceanographic changes that affected the southernmost portion of PNCIMA are presented in Guilbault *et al.* (2003).

Ice loading on the Earth's crust results in depression of the land surface. This is known as glacio-isostatic depression. As glaciers build over an area, they depress the underlying crust lower down into the viscous mantle. The load is transmitted through the upper part of the mantle to push material away from the load and elevate the land surface. This elevated land, peripheral to the ice load, is called a proglacial forebulge and was a large factor in the sea-level history on the BC margin. Another important factor is the removal of water from the oceans of the world to form the continental ice sheets and mountain glaciers which is termed eustatic sea level lowering. This factor contributed up to 110 m of sea level lowering globally during the last glacial maximum 15,000 years ago (Fairbanks 1989).

Relative sea level results from the interplay between isostatic, eustatic and other factors, including tectonism, and is therefore locally quite variable and complex in timing and magnitude at any given location. As ice began to retreat ~ 15,000 yr BP, it retreated most rapidly proximal to the Pacific Ocean. Between 13,000 to 10,000 yr BP, ice was still thick over mainland BC, but had retreated from most of the continental shelf (Josenhans *et al.* 1995; Barrie and Conway 2002). The weight over the mainland, coupled with release of weight over the shelf, caused the shelf area to bulge upwards significantly. It is thought that this proglacial forebulge, combined with global eustatic sealevel lowering caused much of the shelf to be exposed from between 100 and 200 m below current sea level. Figure A.8 shows the area that would likely have been exposed at 100 m of relative sealevel lowering (dark grey). The bulge had a wavelength such that greater uplift occurred further from the mainland.

Fjords along the mainland experienced higher relative sealevels, as illustrated by paleoshorelines found near Kitimat that are now 200 m above sea level (Clague 1985). At the same time, areas of the continental shelf experienced relative sealevels lowered by as much as 200 m and submerged paleoshorelines may be observed, sampled, and radiocarbon dated across much of the region (Luternauer *et al.* 1989a). As the glaciers

retreated and ice melted, more sediments were deposited, and meltwater re-worked much of this sediment on the temporarily emergent shelf. The uplifted continental shelf allowed for much of this re-working, and waves and beach processes remobilized and transported sediments that are now in relatively deep water. The landscapes and seascapes described below, and the distribution of the unconsolidated sedimentary deposits both on land and on the continental shelf, are in large part a result of the last glaciation, and associated sealevel changes.

3.2 Topography of Coastal Landscapes

The coast of BC is made up of three broad physiographic features, (Figure A.9), the Insular Mountains, the Coastal Trough, and the Coast Mountains. The upper portions of PNCIMA watersheds also extend into the Interior Plateau. Along the outer coast, the Insular Mountains consist of the relatively low lying, glaciated mountain ranges of Vancouver Island and the Queen Charlotte Islands. Eastward of these mountains is the Coastal Trough made up of the Hecate and Georgia depressions, including the seafloor of Hecate Strait, through Queen Charlotte Sound and Johnstone Strait to the Strait of Georgia and the lowland areas adjacent to these water bodies. These low-lying basins are adjacent to the Coast Mountains which are steep sided, granite cored mountains. On the far side of these mountains lies the Interior Plateau which consists of high elevation but low relief plains and rolling hills. This pattern of mountains, trough, mountains, plateau is the result of the tectonic forces acting on the Earth's crust caused by the subduction of the Pacific sea floor beneath the North American plate (Thomson 1981) as described in section 2.2.

Glaciation has cut deep, U-shaped valleys into the Coast Mountains, many of which have become long, narrow, steep sided fjords. The resulting coastline is very rugged and mostly inaccessible from the east. Communities are accessed by water and are generally forced to be near the shore since most of the inland area is too steep to use or build on, with the exception of the upper end of the larger fjords.

Clague and Bornhold (1980) provide a detailed summary of the littoral processes affecting the BC coast and a discussion of the resulting coastal landscapes and shoreline types. They note that, although there are a variety of energy levels found along the coast, ranging from the very high energy areas of the exposed coast to low energy protected channels, straits, inlets and fjords, the dominance of resistant rock types along the coast coupled with very low input of terrestrial sediments results in little or no littoral sediments in most areas. The lack of sediment input is a result of the relatively few large rivers emptying into the coastal waters, and the presence of deep fjords or basins which allow settling of much of the sediment before it can reach the outer coast. The result is a coastline dominated by rocky shorelines with rare and generally small pockets of gravel or sand beaches which are mostly found along the lowlands of the Coastal Trough or places where cliffs of glacial sediments are actively eroding and providing an ongoing source of sediments.

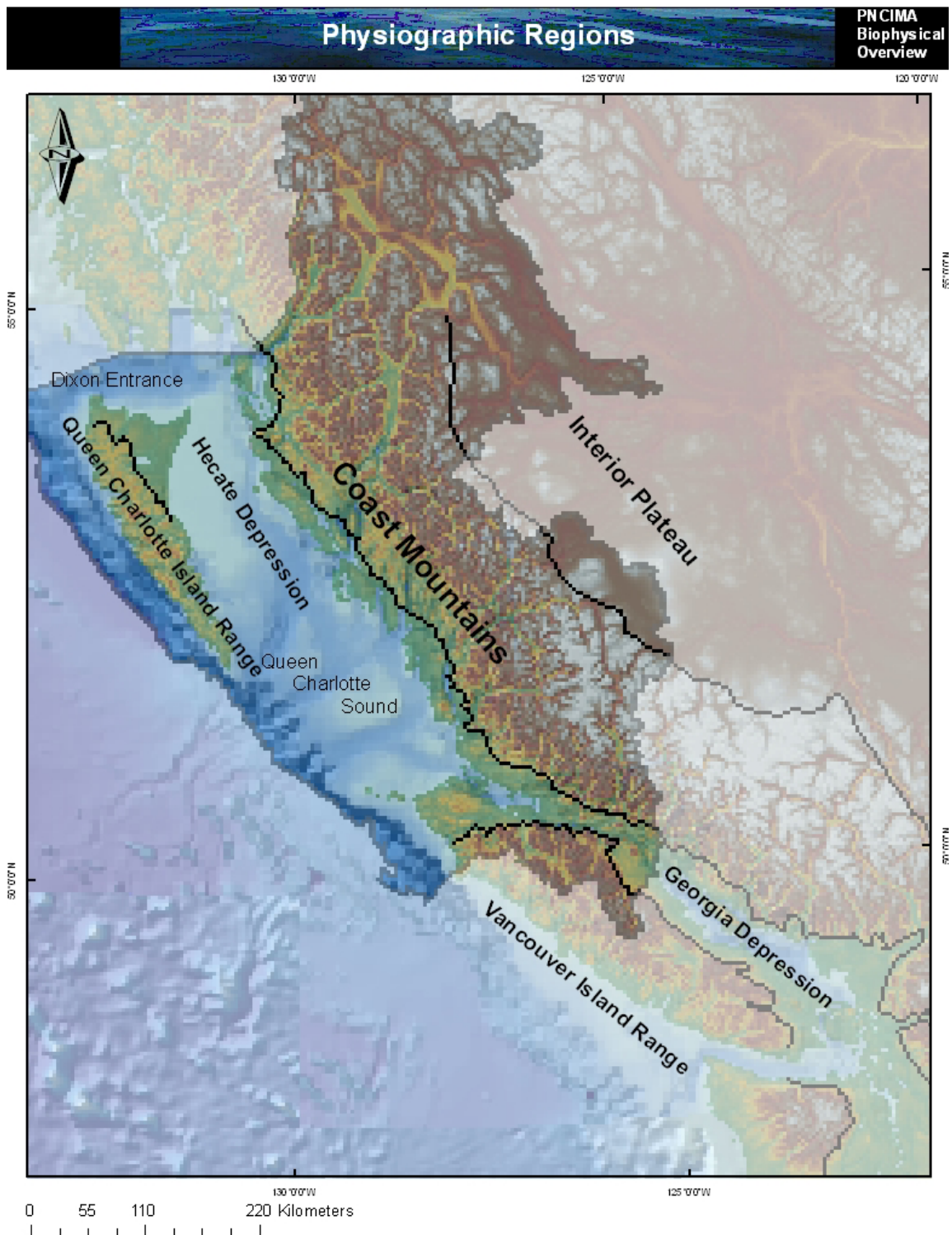


Figure A.9 Physiographic regions of Coastal BC. Topographic and bathymetric image from Natural Resources Canada (regions adapted from Clague and Bornhold 1980; Thomson 1981).

The provincial government, in association with Coastal and Ocean Resources Inc., has produced GIS data of shoreline types for the entire BC coastline based on the analysis of video footage taken from flights over the shorezone. These data are most useful at a fine scale and are being made publicly available via http://maps.gov.bc.ca/imf406/imf.jsp?site=dss_coastal.

3.3 Watersheds and Hydrology

PNCIMA includes a portion of what is termed the Coastal Drainage, one of the nine drainage basins of BC, as well as the drainage basins of the Skeena and Nass rivers and the small island drainages. These drainage basins are divided into Major Watersheds which are in turn subdivided into the Watershed Groups as illustrated in Figure A.10. These watershed divisions are commonly used in terrestrial planning and management processes at all levels of government.

The majority of PNCIMA receives limited fresh water from relatively short, steep coastal drainage basins or from extremely short and relatively low lying drainage basins found on the Queen Charlotte and Vancouver islands. This is in sharp contrast with the Strait of Georgia to the south which is strongly influenced by the huge Fraser River drainage basin (Figure A.11). However, the northernmost portion of PNCIMA (Dixon Entrance) receives significant fresh water from the Skeena and Nass drainage basins. Figure A.12 shows that these drainage basins produce about 1/3 the volume of the Fraser River.

Figure A.12 also shows the hydrographs of selected rivers, which appear to fall into three types reflecting the hydrodynamics of their watershed. The first type is the snowfall dominated rivers. This is reflected in the larger rivers (Skeena, Nass and Fraser) which generally achieve their highest flows during spring freshet due to the initial melt of the snow pack, and their flow rates taper off through the summer. This is likely seen in the larger rivers because of the large surface area of their drainage basins allowing them to accommodate large volumes of snow. Flows for these rivers decrease during the fall (with some peaks for fall storms) and are generally lowest in the winter when much of their watershed is cold enough to be accumulating snow.

The rainfall dominated rivers show almost the opposite trend in that their highest flows are during the fall and winter storm seasons while spring and summer show a steady decrease in flow volume. The small and low elevation watersheds of the Queen Charlotte and Vancouver islands tend to produce rainfall dominated rivers, especially as they receive less overall precipitation and temperatures are made so mild by the influence of the ocean that they accumulate relatively little snow.

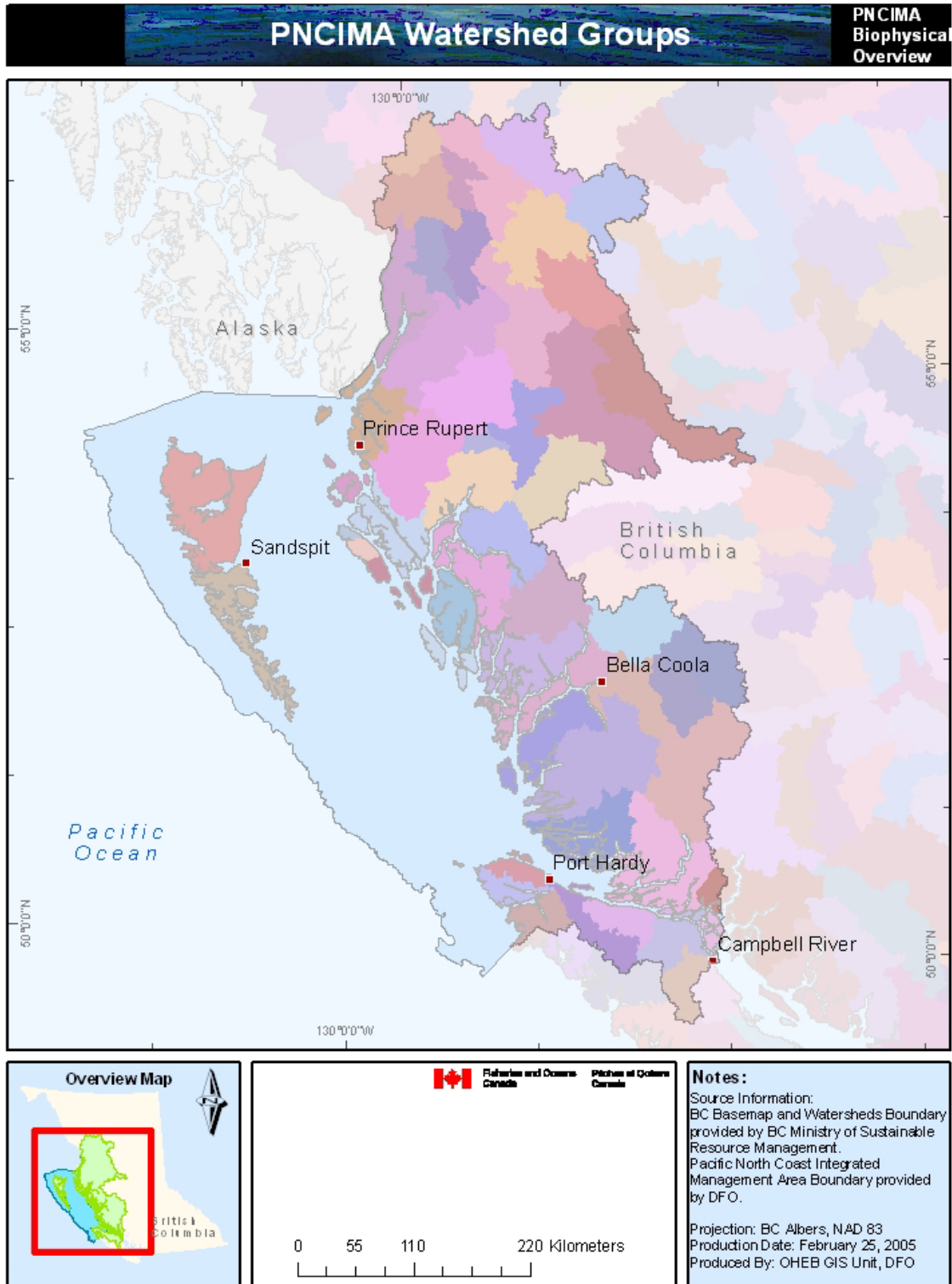


Figure A.10 Watershed Groups in PNCIMA (data from the BC Ministry of Sustainable Resource Management, Digitized from Environment Canada map sheets).

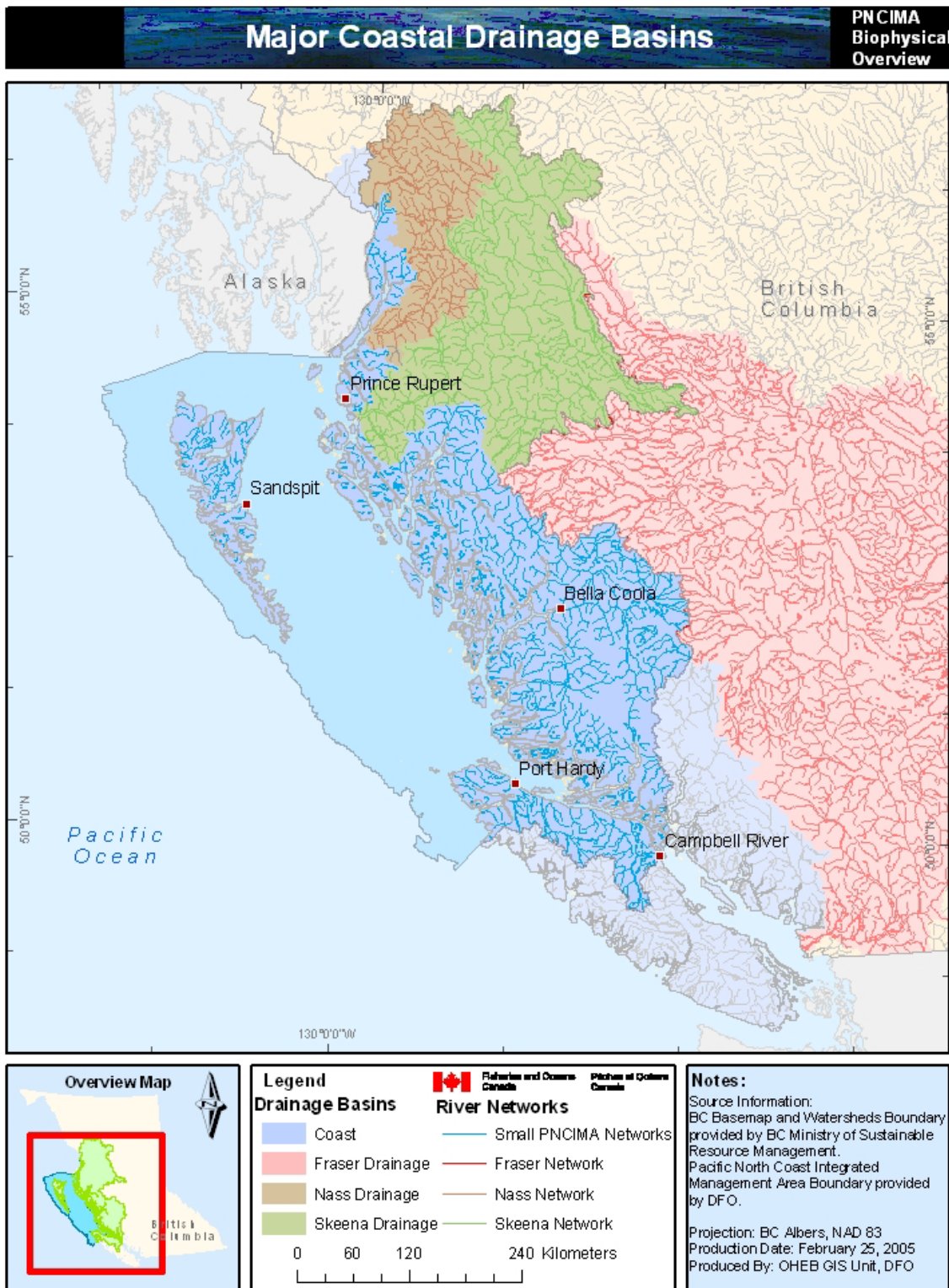


Figure A.11 PNCIMA drainage patterns and adjacent major drainages (data from the BC Ministry of Sustainable Resource Management and Natural Resources Canada).

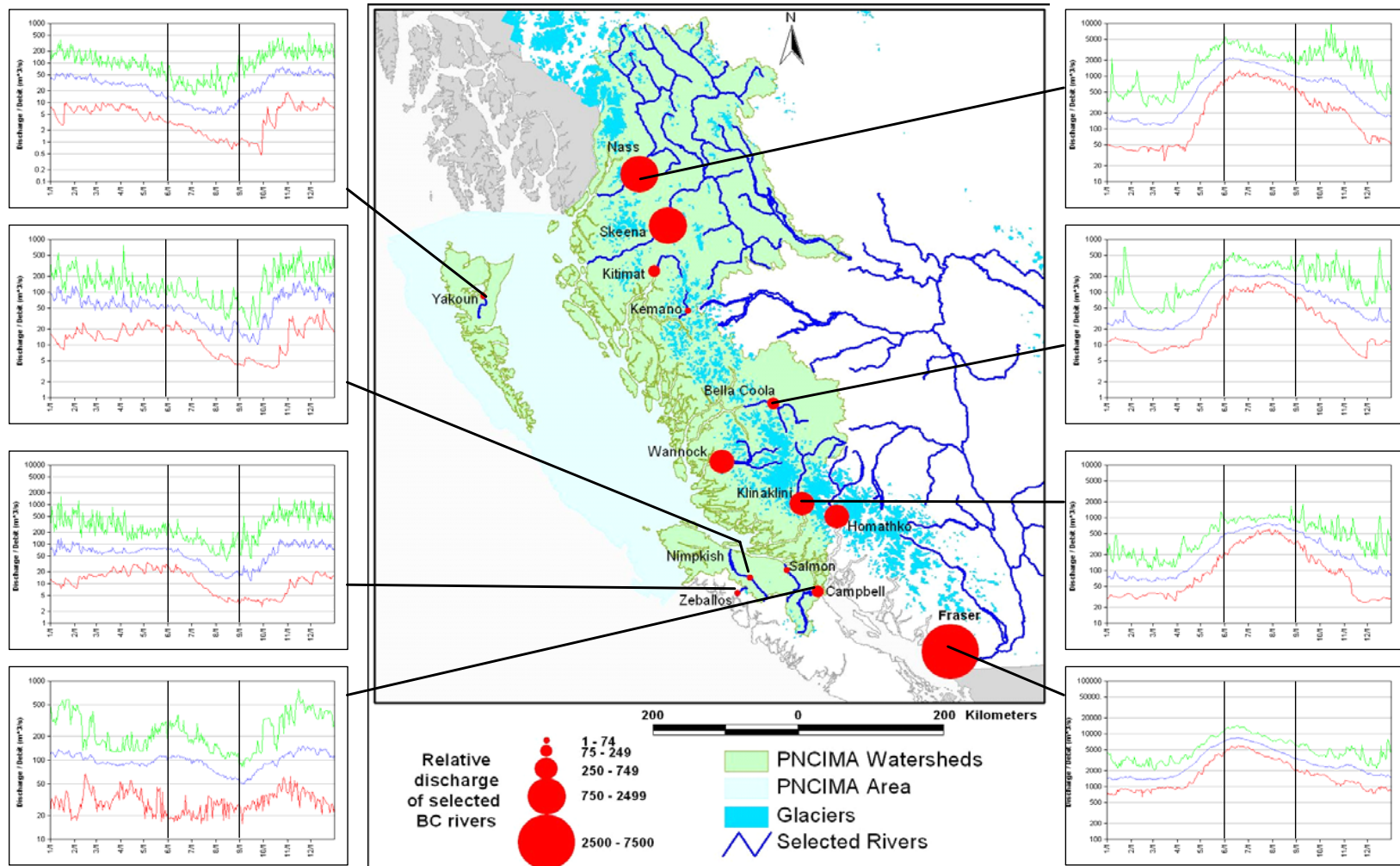


Figure A.12 Maximum (green curve), mean (blue curve) and minimum (red curve) average annual river discharge from selected rivers of Coastal BC and hydrographs of their seasonal discharge (for details of discharge see http://scitech.pyr.ec.gc.ca/climhydro/welcome_e.asp, discharge data from Environment Canada's HYDAT CD ROM).

A third hydrograph pattern arises with the rivers of the central portion of the coast. These rivers experience the spring freshet as their steep watersheds would be capable of accumulating significant snowfall at high elevations. However, throughout the summer there is little or no slackening of flow volumes and in some cases there is slight increase with warmer late summer weather (see Klinaklini in Figure A.12). This is likely a result of the abundant and large glaciers found at the heads of the central coast watersheds which would achieve peak melt during the hottest part of the summer. Because their drainage basins are small, the effect of the glaciers is not lost in comparison to a huge snowmelt in the spring. A further result of their lower overall flow volumes is that the effect of fall and winter storms on the hydrograph is more pronounced compared to larger rivers.

Two important points arise from this hydrologic information. Firstly, freshwater influence is very significant to physical oceanographic processes and biological productivity (as discussed in Appendices C and D). This suggests that there may be significant differences between the northernmost portion of PNCIMA with its stronger, spring timed freshwater influence, as compared to the south and central portions with lower overall flows and more steady rates throughout the summer.

Secondly, if climate change progresses as is predicted (see discussion in Appendix B), one significant change to freshwater flows would be a change in the hydrologic profile of some of these rivers. Two consistent changes have been noted in northern BC rivers that are thought to be related to climate change (Whitfield 2003). One is that overall streamflows have increased. This is thought to be a result of higher temperatures causing melting of formerly permanent snow, ice or permafrost. This is necessarily a short term effect as once those reserves are used up, streamflows will decrease, possibly dramatically. At that point those streams will likely be more strongly influenced by rainfall than by meltwaters. Coastal streams in particular have shown increases in winter runoff and decreases in early spring and late summer discharge (Whitfield *et al.* 2003). The second effect is a steady movement of spring freshet to earlier and earlier peaks times. This would be due to increased temperatures causing earlier snowmelt. This may have significant impact on ecosystem function, particularly as it is often coupled with earlier and more extreme summer and fall minimum flows. Overall it was noted that changes in temperature is the main factor affecting stream flow, not changes in precipitation (Whitfield 2003).

Modelling has predicted two further effects of climate change on streamflow. There is expected to be an increase in the frequency, and for snowmelt dominated streams a summertime increase in magnitude, of flood events (Whitfield *et al.* 2003). Over a longer time scale, modelling of the Fraser River has suggested that by 2080 the Fraser River will behave as a rainfall dominated river for 13% of the years (Morrison *et al.* 2002). This is a very significant change and would undoubtedly have significant effects on the Strait of Georgia ecosystem. The Skeena and Nass rivers currently behave much like the Fraser River (snowmelt dominated) and so may experience similar changes which would affect the northern portion of PNCIMA significantly.

3.4 Bathymetry and Seascapes

The distribution of marine geoscience data is presented in Figures A.13 and A.14. These data bear on geomorphic and bathymetric understanding of the region as well as the glacial history and the geology of the seabed. They also illuminate where data gaps exist in the understanding of the geologic development of the region. The marine portion of PNCIMA includes waters overlying the central and northern continental shelf and slope of BC. This portion of the shelf is dominated by a series of shallow banks in the understanding of the geologic development of the region.

The marine portion of PNCIMA includes waters overlying the central and northern continental shelf and slope of BC. This portion of the shelf is dominated by a series of shallow banks separated by deep troughs (Figures A.15 - A.17). Goose Island and Cook banks are relatively shallow (< 100 m), while North Bank is deeper (< 200 m), and Dogfish Banks are very shallow (< 20 m). Moresby, Mitchell's and Goose Island troughs separate the four central banks with depths to approximately 400 m where they reach the continental slope. Dixon Entrance (Figure A.15) is a relatively deep portion of the shelf open to the Pacific Ocean but submarine sills formed by igneous bedrock are transverse features within the trough that likely play an important role in deflecting bottom currents. The steep and rugged continental slope is included in PNCIMA, whose westernmost boundary is at the base of the slope as defined by the slope analysis of Jeff Ardron (Johannessen *et al.* 2004).

Medium-scale features on the continental shelf seafloor have been studied and mapped (Barrie *et al.* 1988; Luternauer *et al.* 1989b; Moslow *et al.* 1991; Barrie *et al.* 1990a; 1990b; 1990c; 1991a; 1991b; Barrie 1988; Bornhold and Barrie 1991; Barrie and Conway 2001). The most recent compilation of these seafloor features is shown in Figure A.17. Detailed seabed survey work in the mid 1980s resulted in the discovery of huge siliceous sponge reefs (Hexactinellida) in the troughs of Queen Charlotte Sound and Hecate Strait (Figures A.18 and A.19)(Conway *et al.* 1991; DFO 2002; GSC 2001a; 2001b). The BC sponge reefs are thought to be unique in the modern world, although the reef forming order of sponges, the Hexactinosida, built extensive reefs during the Upper Jurassic until the Late Cretaceous (between 150 and 65 million years ago)(Conway *et al.* 1991). These rare cold water reefs are now believed to be significant habitat for many marine organisms, particularly rockfish, and may be especially important during early life stages (Conway 1999; Jamieson and Chew 2002). Further research has recently been focused on the oceanographic setting (Conway *et al.* 2005a; 2005b; Whitney *et al.* 2005) and the ecology of the reefs (Cook 2005).

New survey and mapping techniques, particularly multibeam sonar, are allowing the high resolution mapping and characterization of the seabed. Collaboration between researchers with GSC and the Canadian Hydrographic Service (CHS) is producing high-resolution bathymetry and backscatter datasets within PNCIMA. The distribution of sponge reefs in the four main reef complexes has been defined by multibeam surveys (Figure A.17)(Conway *et al.* 2005a).

Multibeam swath bathymetry surveys require extensive survey ship time, so the mapping of the entire continental shelf of BC will require several years of sustained effort. The areas within PNCIMA that have been surveyed to date by multibeam bathymetry are shown in Figure A.14.

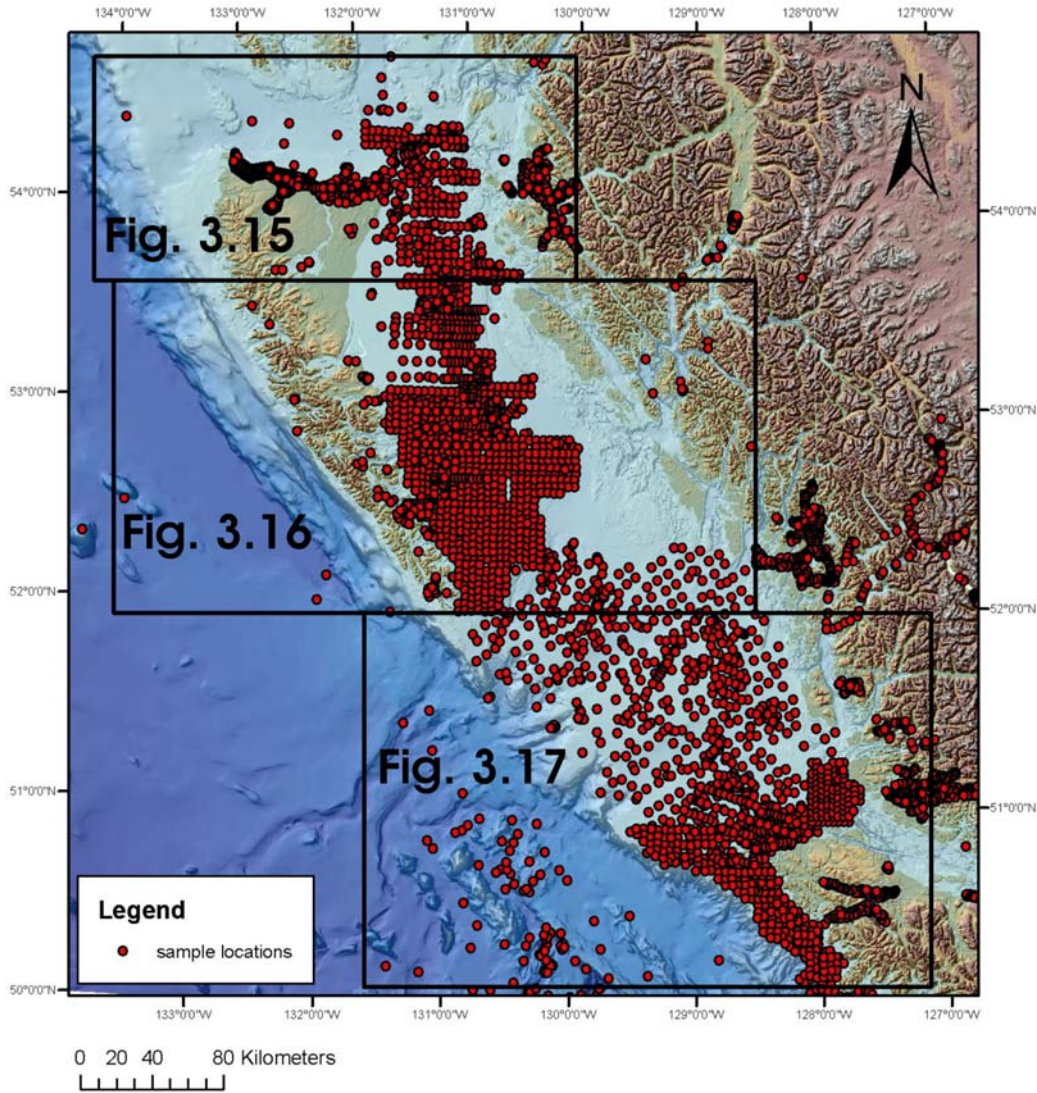


Figure A.13 Distribution of GSC (Geological Survey of Canada) collected core and grab samples in the PNCIMA region. Inset boxes show locations of Figures A.15-A.17.

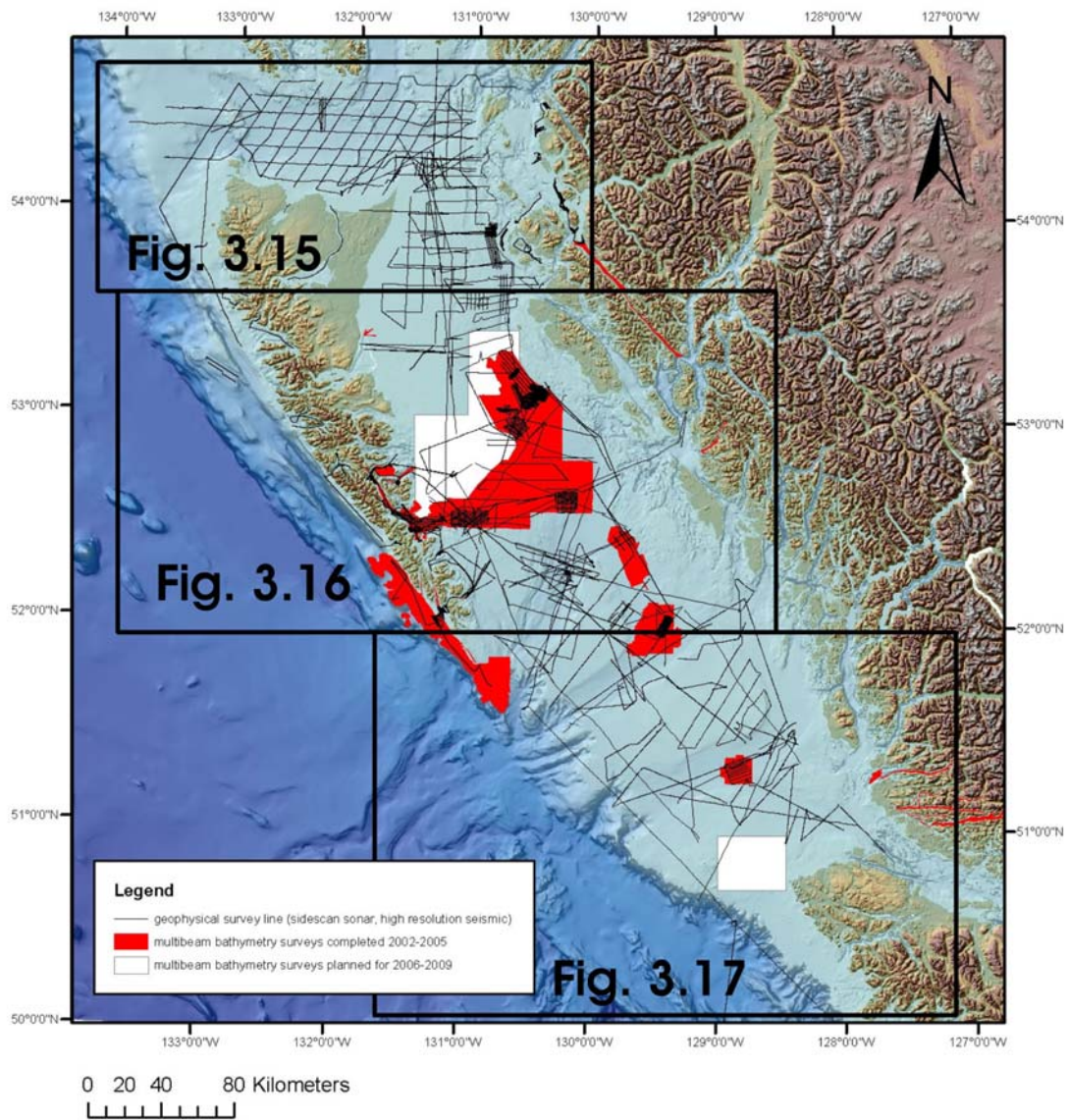


Figure A.14 Location of geophysical tracklines collected by GSC and multibeam datasets acquired by CHS (Canadian Hydrographic Service) in PNCIMA. Inset boxes show location of Figures A.15-A.17.

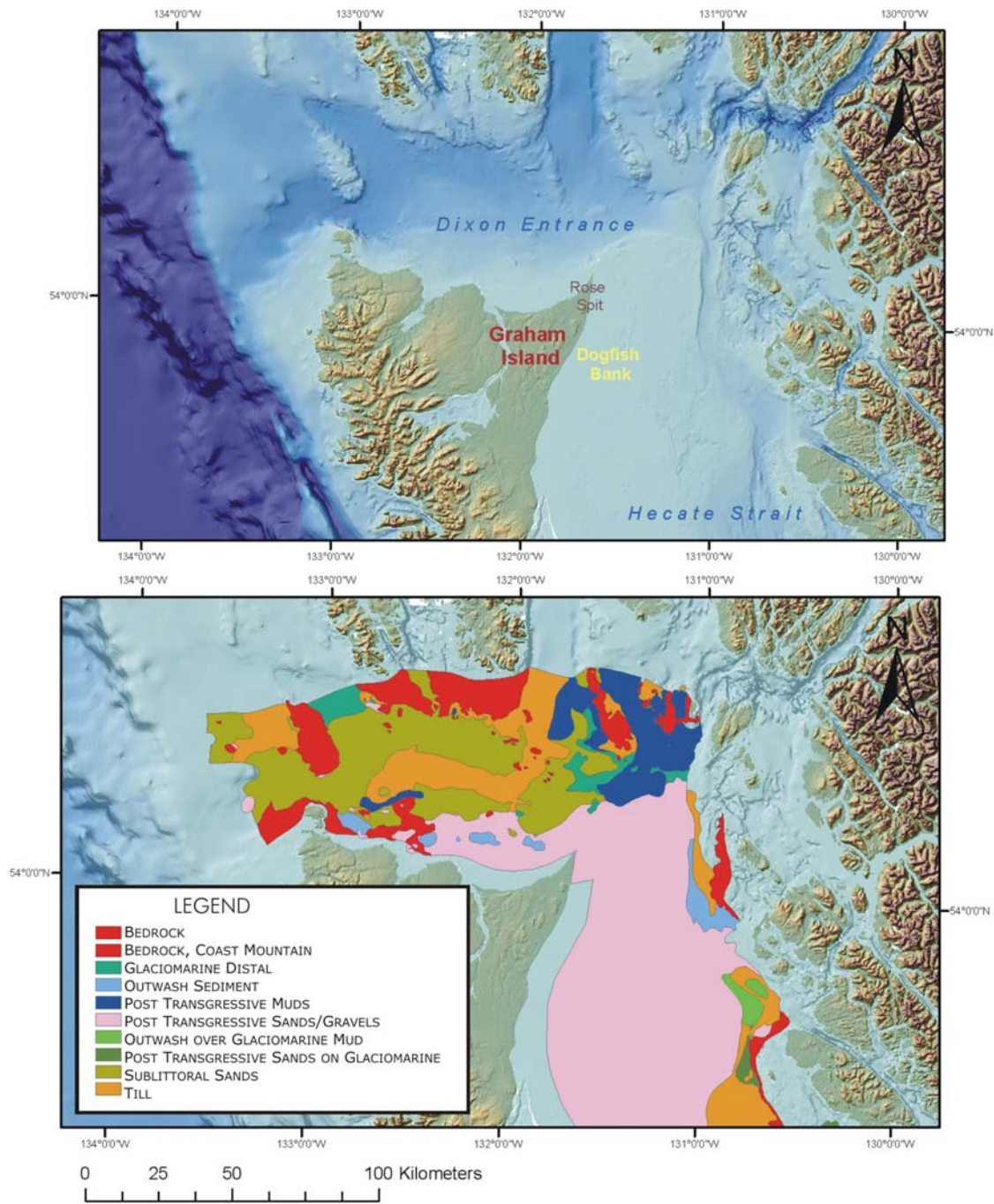


Figure A.15 Seafloor morphology (above) and geology (below) of the Dixon Entrance and northern Hecate Strait (after Barrie and Conway 1999).

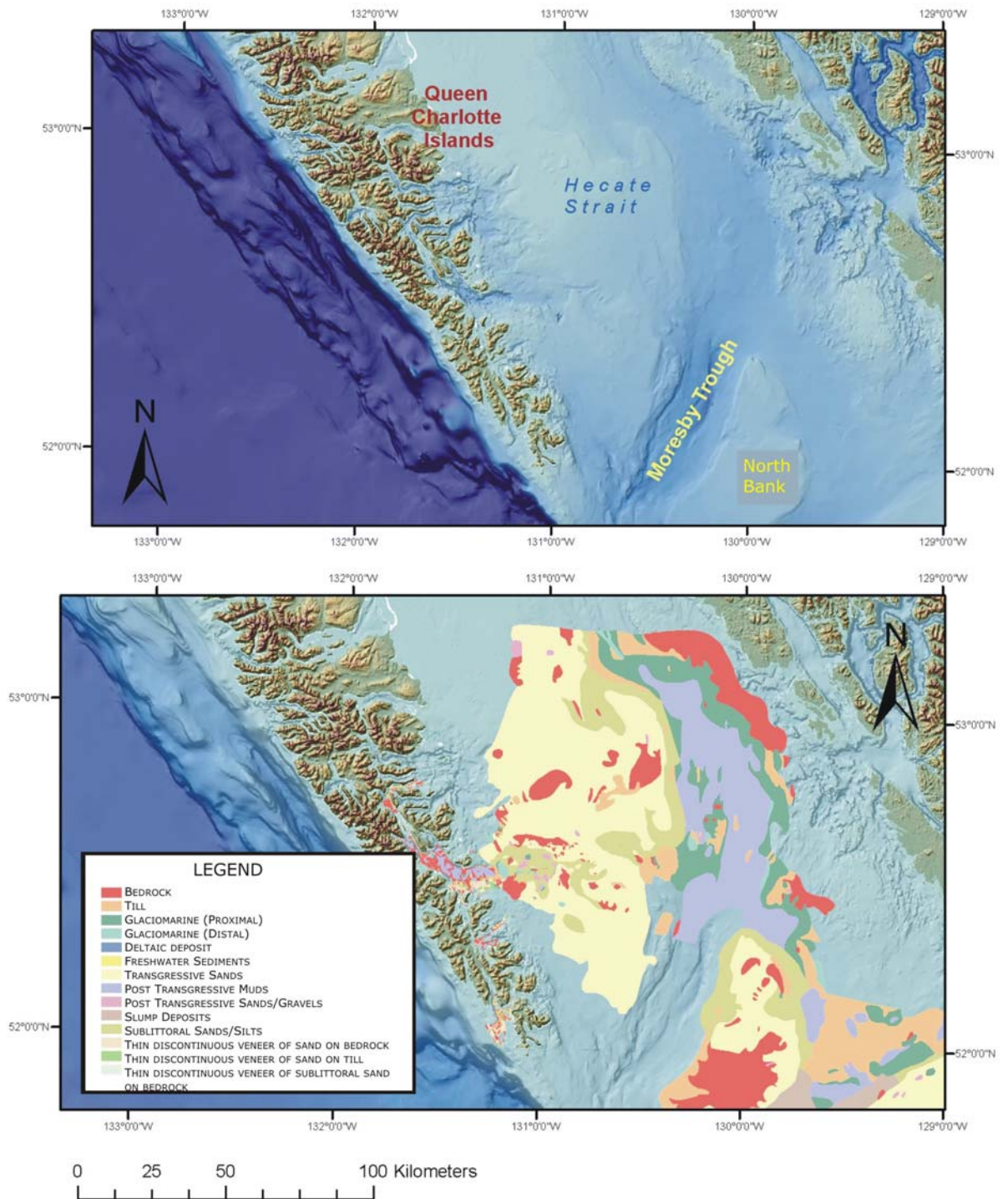


Figure A.16 Seafloor morphology (above) and geology (below) in Hecate Strait (after Josenhans 2006a).

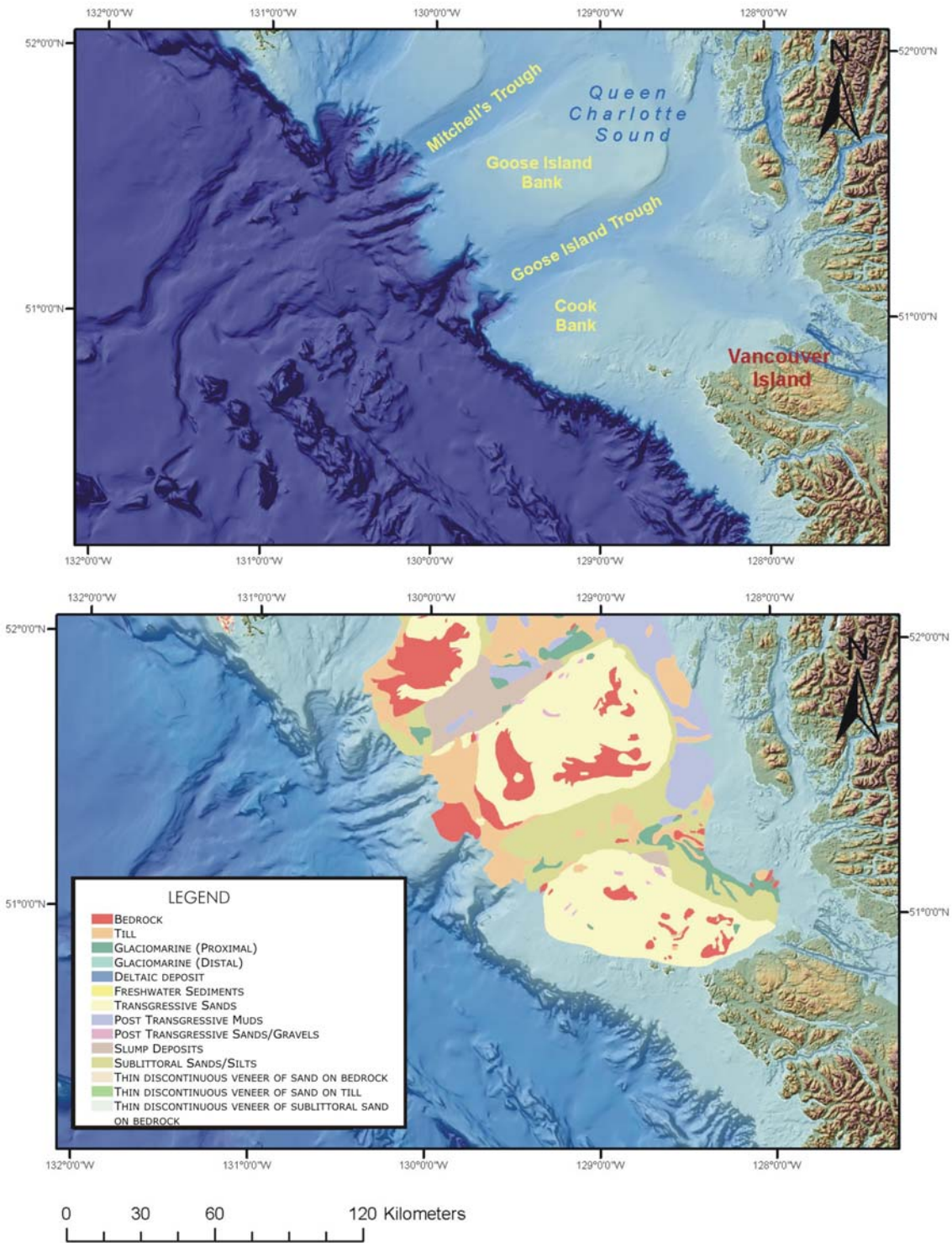


Figure A.17 Seafloor morphology (above) and geology (below) in Queen Charlotte Sound (after Josenhans 2006b).

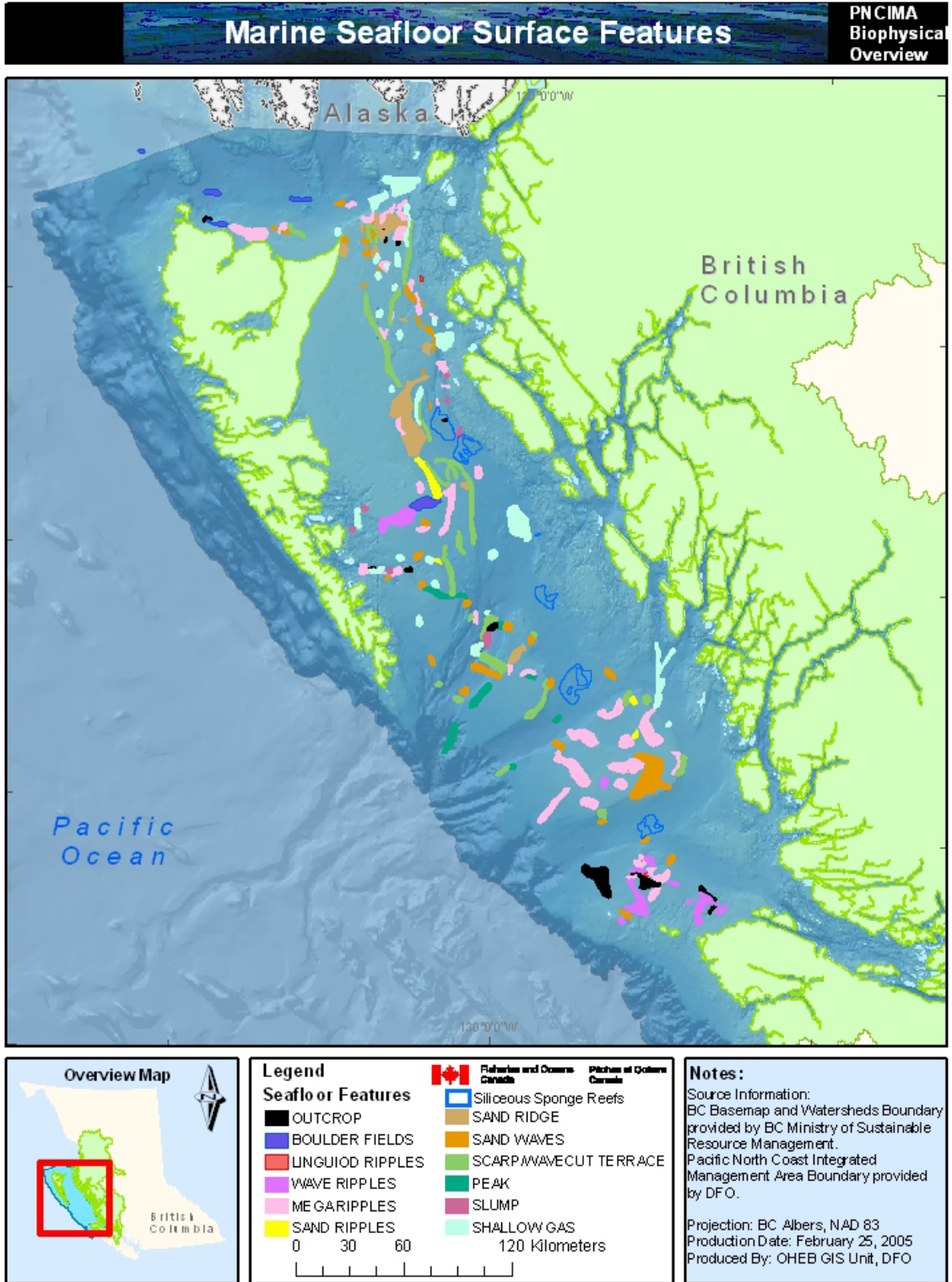


Figure A.18 Known surficial seafloor features in PNCIMA (data from Natural Resources Canada 2005).

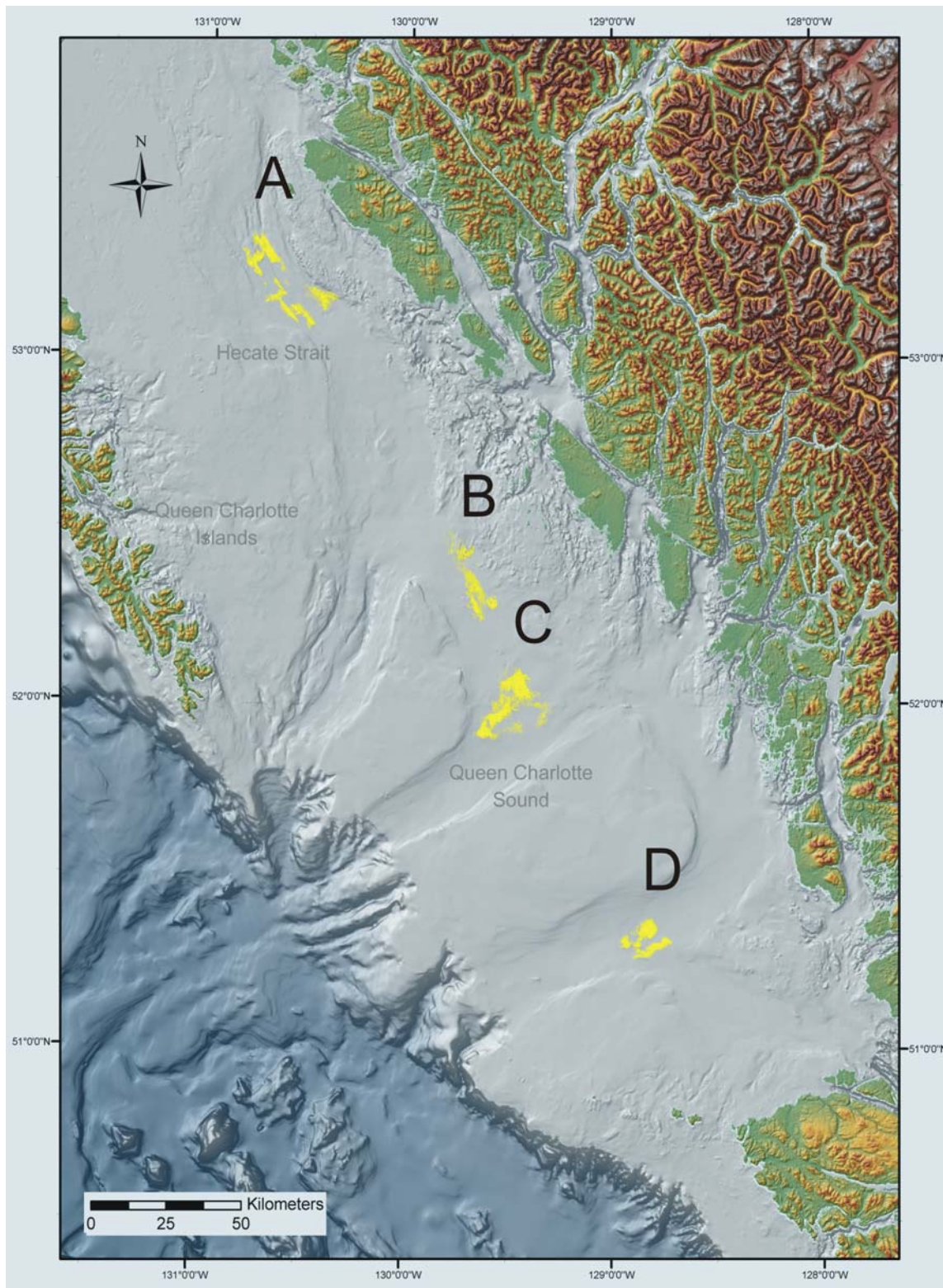


Figure A.19 Distribution of hexactinellid sponge reefs in the Queen Charlotte Basin. Letters refer to the various reef complexes.

4.0 SEDIMENTOLOGY

4.1 Marine Geology and Sediments

The Geological Survey of Canada (GSC) has conducted most of the research on the marine geology of the continental shelf of BC. Extensive sediment sampling has been accomplished by the GSC over many years. These core and grab samples locations are shown in Figure A.13. An extensive network of geophysical survey lines has also been collected and compiled over the last 25 years by the GSC and these data form the basis for a regional understanding of the geology of the PNCIMA region (Figure A.14). Recently compiled geological maps (Josenhans 2006a; 2006b) of PNCIMA (Figures A.15-A.17) show a clear trend for fine grained sediments to be found in the deep troughs and coarser grained sands, gravels, or bare bedrock to be found on the steep slopes and shallow tops of the banks.

Starting in 2002, sophisticated multibeam sonar technology has been applied to PNCIMA region (see section 1.4), and consequently our detailed knowledge of seafloor features, geohazards and sediment characteristics is advancing rapidly. Multibeam coverage to date is shown in Figure A.13. The multibeam program is an ongoing joint project of the GSC and the Canadian Hydrographic Service. Magnetic and subbottom profile data (3.5 kHz) are being collected simultaneously during these surveys. Previous work from the 1980s and 1990s has been summarized (Luternauer and Murray 1983; Barrie *et al.* 1991a; Bornhold and Barrie 1991) and maps of the area have been published (Barrie *et al.* 1990a; 1990b; 1990c).

The distribution of surficial sediments has been controlled by several factors, including; the effects of repeated Quaternary glaciations, sea level changes which accompanied the most recent glaciation, the present day wave and current regime that controls sediment transport, and the isolation of much of the shelf from a significant sediment supply. The Queen Charlotte Sound and Hecate Strait continental shelf is characterized by shallow banks and deep troughs (Figures A.15-A.17) that were excavated by successive glaciations (section 1.0). The most recent glaciation deposited sediments by a variety of glacial-marine processes following a sequence of ice proximal, coarse sediments through ice distal, fine sedimentation (Barrie and Conway 2002). These processes result in troughs that are floored by relatively thin recent muds that sit on up to 100 m of glacial sediments (Barrie *et al.* 1991a; 1991b). As glaciers receded to the mainland as an iceberg calving ice-front (Barrie and Conway 2002), meltwaters re-worked these sediments in shallow waters and a simultaneous local drop in sea level (Luternauer *et al.* 1989a) exposed the banks to littoral processes so that surficial sediments in these areas were remobilized to form large coastal features such as wave-cut scarps and terraces (Barrie 1988), spits and beaches (Josenhans *et al.* 1995), and deltas (Barrie and Conway 2002). In addition, in the troughs, icebergs scoured the seabed in deeper-water areas during the same time interval, creating the habitat upon which sponge reefs would subsequently develop. These unique reefs are restricted to such glacial substrates (Conway *et al.* 1991; 2005a).

In recent (Holocene) times, hydrodynamic energy has remained high on most of the continental shelf given the exposure of most of the region to Pacific Ocean swell and an intense tidal regime (Barrie *et al.* 1988; Crawford 2001). This particularly affects the shallow banks which continue to be covered in mobile sand and gravel deposits. With the establishment of Holocene sea levels, much of the recent sediments derived from the continental landmass are trapped in the fjords and channels bordering the mainland that act as settling basins (Luternauer and Murray 1983), so that much of the continental shelf receives no appreciable new sediments from mainland sources, but is sediment starved. The preponderance of rocky shorelines on the BC coast and the relatively thin layer of modern muds found in the deeper troughs and basins of the continental shelf are indicative of this paucity of sediments. This relict, sediment starved condition has also contributed to the development of the extensive sponge reefs in the shelf troughs that are founded to a large extent on exposed 15,000 year old iceberg furrows. The limited sediment input may be a critical factor in the development of hexactinellid sponge reefs described above, which could be subject to smothering by too much sediment input (Conway *et al.* 1991). More recent work suggests that some sponge populations, such as those found off the Fraser River, may be able to tolerate relatively high suspended sediment concentrations (Conway *et al.* 2004).

The Dogfish Banks area of Hecate Strait is an area that is unique on the BC shelf for several reasons. It is an actively eroding coastline on the east side of Graham Island, and the shallow nearshore seabed of the bank (Figure A.15) is regularly reworked by intense southeast storms. The nearshore, the intertidal zone and the shoreline are a dynamic system where up to 12 m of coastal erosion has been measured in one year (Barrie and Conway 2002). Rose Spit, the northeast point of Graham Island, is a constructional feature that has been growing for several millennia at least, as the eastern Graham shoreline erodes (Barrie and Conway 1996a), while the northern side of Graham Island has been growing for the past 5,000 years through onshore transport from Dixon Entrance and the accumulation of sediment in wide beaches and a dune system (Harper 1980). It has been suggested that localized tectonism may play a role in these sediment transport phenomena (Harper 1980; Barrie and Conway 1996b), though vertical tectonic movements are thought to be at least an order of magnitude lower than isostatic movements shortly after deglaciation (Barrie and Conway 2002, and references therein). Sediment dynamics on this vulnerable, unconsolidated coastline are thus quite different than most of the PNCIMA region that is dominated by rocky indented shores, and sparse nearshore and coastal sediments.

Although relatively little bathymetric surveying has been done in Dixon Entrance, compared to the rest of PNCIMA, it has been determined that the seafloor is underlain by thick glacial deposits (Figure A.15) (Barrie and Conway 1999). The glacial sediments are overlain by a thick layer of reworked muddy sand (transgressive sand) that remains the dominant exposed sediment, suggesting that energy levels have remained high since the end of glaciation. Although in shape it resembles one large trough, Dixon Entrance is broken into basins by three cross-cutting volcanic sills (Barrie and Conway 1999).

Recent work by DFO and GSC scientists on the relationship between groundfish species and substrate type appears to indicate that certain species show a preference for coarse sands and gravels, while others seem to prefer finer grained substrates such as sandy silts or muds. This is indicated in the species composition of trawl catches over the banks vs. within the troughs (A. Sinclair, DFO, Pacific Biological Station, Nanaimo BC. pers. comm., 2003). This interpretation is complicated by the tendency for certain species to prefer certain depths while substrate types are also segregated by depth (Sinclair *et al.* 2005).

Linkages between the regional physical and chemical oceanography and sponge reef development have recently been examined. These results indicate that the siliceous sponge reefs exist in a silicate rich environment that is enriched by wind-driven downwelling of productive surface waters (Whitney *et al.* 2005), and that tidally modulated transport of fine particles on the shelf and bathymetrically focussed delivery of nutrients and sediments enhances the growth of the sponge reefs. The canyon setting of the main reef complexes (Figures A.18 and A.19) acts to funnel nutrients and sediments to reef sites (Conway *et al.* 2005b). The “sediment” particles captured at the reefs have a large proportion of biogenic component of diatoms and foraminifera, accounting for up to 30 % of the reef sediments as measured in core traps (Conway *et al.* 2001) and up to 70 % as measured in sediment traps (Geological Survey of Canada - Pacific unpublished data). This suggests direct linkages between the surface water processes of primary productivity (photosynthesis) to the benthic ecosystem and sponge reefs.

4.2 Terrestrial Soils and Sediments

Soil information in Canada exists at both fine and coarse scales. The National Soils Data Base contains data from detailed soil surveys across Canada, but these fine scale surveys target agricultural areas, so coverage of PNCIMA is almost non-existent. However, at a coarser scale, the Canadian Soil Information System has used regional information to produce the Soil Landscapes of Canada which are mapped as polygons at a 1:1 million scale.

PNCIMA watersheds are dominated by the bare rock and ice of the higher elevations of the Coast Mountains. Aside from that, low organic content soils dominate with a few areas of organic soil in low-lying coastal regions. The soil development dataset (Figure A.20) classifies the dominant soil in the polygon according to the Canadian System of Soil Classification (Soil Classification Working Group 1998). PNCIMA watersheds are almost entirely covered by only three soil types; two kinds of Podzols and an Organic soil. Descriptions of these three soils are summarized below from the 3rd edition of the Canadian System of Soil Classification (Soil Classification Working Group 1998).

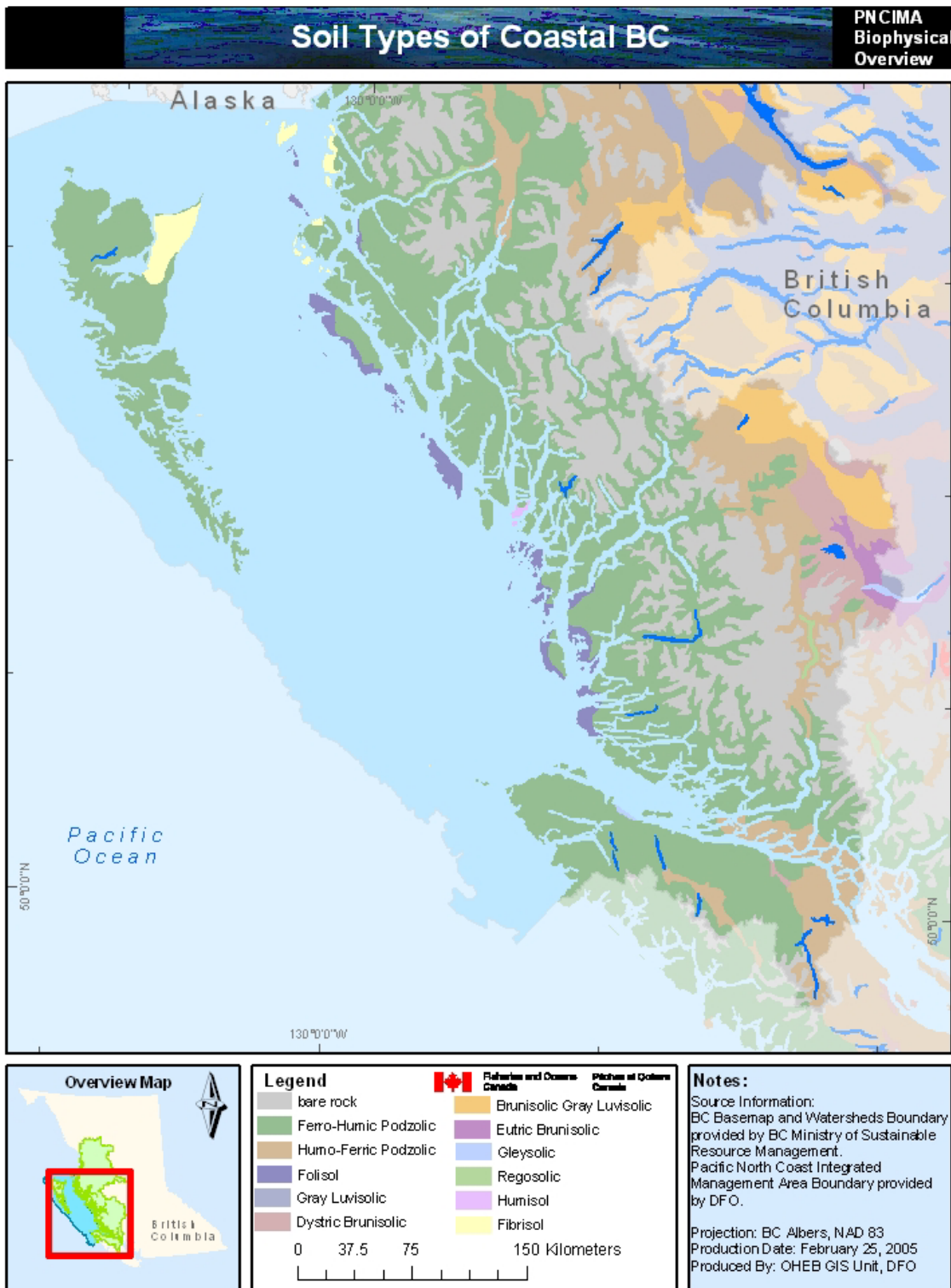


Figure A.20 Map of soil development types. Data from the National Soils Data Base, (see Agriculture and Agri-Food Canada 2005 for full soil type descriptions).

The National Soils Data Base contains further detailed information about soils and soil chemistry as well as the addition of climate data. This allows for a greater range of possible uses and analyses. For example, the terrestrial Biogeoclimatic Zones of BC (Meidinger and Pojar *eds.* 1991), are a form of ecosystem definition based on a combination of vegetation, soil, and climate (which indirectly includes elevation and latitude).

5.0 RESOURCE POTENTIAL

5.1 Offshore Oil and Gas

This topic is dealt with in further detail in the PNCIMA Marine Use Analysis (Fisheries and Oceans Canada 2007). For the completeness of this chapter a short summary is provided here.

On Canada's Pacific margin there are four relatively large sedimentary basins that could potentially contain petroleum (Figure A.21). These basins are geologically young (Georgia <100 Ma (million years ago), Tofino < 60 Ma, Queen Charlotte < 30 Ma, Winona < 6 Ma) (Hannigan *et al.* 2001). Three of the basins are part of the Pacific continental shelf (Queen Charlotte, Tofino, and Georgia) and these basins have been partially explored. The Winona basin is relatively unexplored and lies at the base of the continental slope in deep water.

Median in-place estimates of petroleum potential in these basins given in Table A.0 are based on complex analyses of the basins, but no significant oil or gas has yet been discovered. The Geological Survey of Canada has published work on the geology and hydrocarbon potential of the basins, most notably Woodsworth (1991) and Hannigan *et al.* (2001; 2005). All of these reports agree that the largest and most prospective basin is the Queen Charlotte Basin.

Table A.0 Median in-place estimates of the petroleum potential in the four west coast basins (data summarized in Hannigan *et al.* 2001).

Resource Type	Georgia Basin	Tofino Basin	Queen Charlotte Basin	Winona Basin
Oil	No estimate provided	No estimate provided	1.56 billion m ³ (9.8 billion barrels)	No estimate provided
Gas	185 billion m ³ (6.5 trillion ft ³)	266 billion m ³ (9.4 trillion ft ³)	734 billion m ³ (25.9 trillion ft ³)	

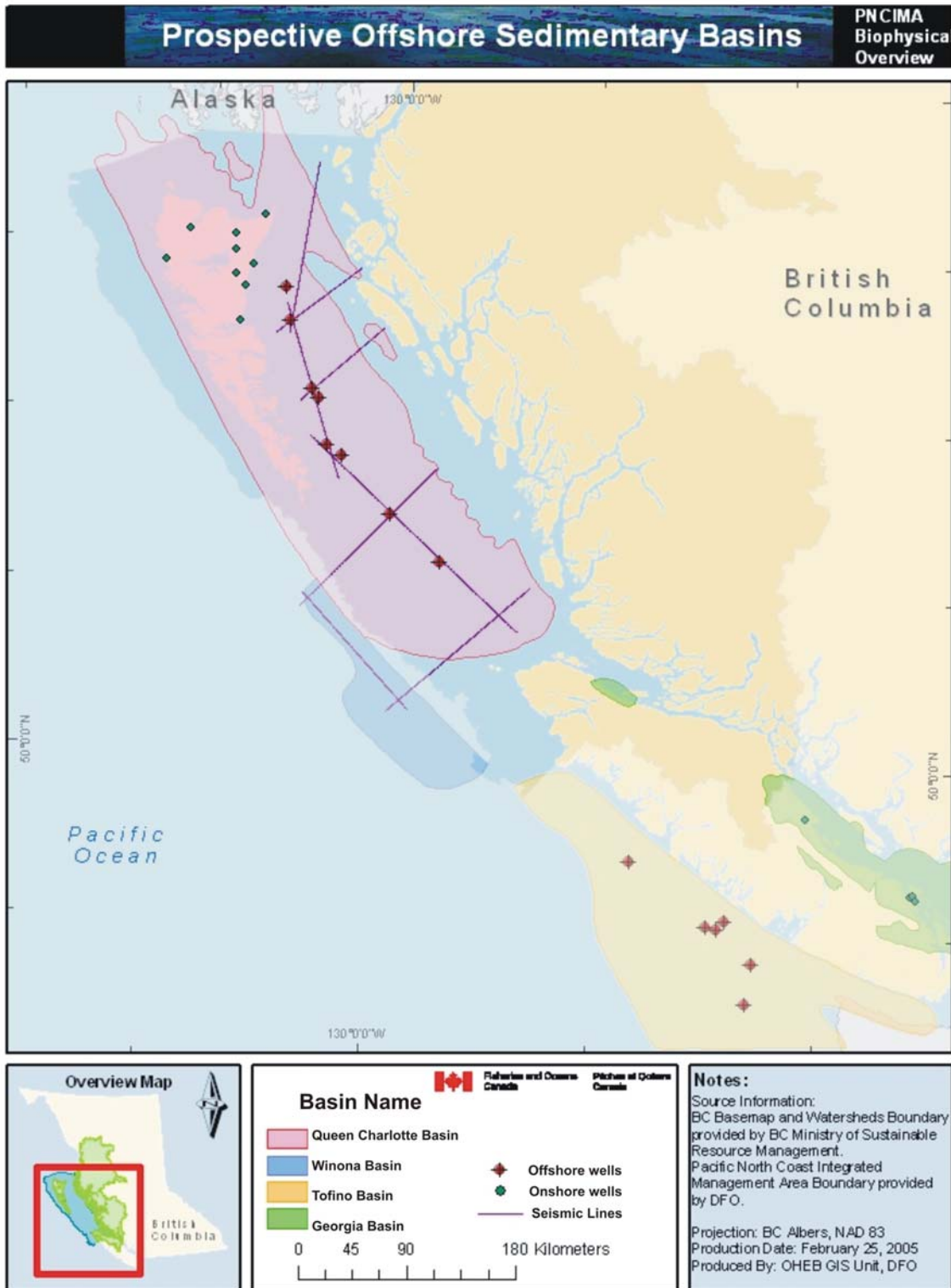


Figure A.21 The four major sedimentary basins on the Pacific Margin of Canada with the location of past exploratory onshore and offshore drill wells and multichannel seismic lines shot by the GSC in 1988 (data from BC Ministry of Energy and Mines). Not shown is industry seismic data collected in the 1960s and 1970s.

There are actually two basins in the Queen Charlottes region (Hannigan *et al.* 2005), the older and less significant Hecate Basin, which is Cretaceous in age, and the younger, Tertiary age, Queen Charlotte Basin (QCB). The QCB is an upper Tertiary strike-slip basin that developed in response to transtensional and transpressional Pacific-North America plate interactions (Lewis *et al.* 1991; Rohr and Dietrich 1992; Rohr and Currie 1997). The basin encompasses some 40,000 km² and is underlain by Mesozoic and lower Tertiary volcanic, plutonic and sedimentary rocks. QCB basin-fill sediments were derived from variable source areas and directions. In detail, the basin consists of a series of separate or partly coalesced strike-slip sub-basins, which developed across a 150 km-wide, plate margin parallel shear zone (Rohr and Dietrich 1992; Dietrich 1995). The subbasins are commonly half grabens bound by normal or oblique slip faults. Overlying the sediments that infilled the lower part of the basin as it was being faulted (syn-rift sediments) are relatively undeformed clastic sediments that are more laterally continuous and which drape the deeper structures. The complex tectonic history of the region has formed many structures within the basin that could act as petroleum traps. Although no oil or gas pools have yet been discovered, indications of oil have been encountered in exploratory wells, and oil, tar, or gas seeps have been found on the Queen Charlotte Islands (Hamilton and Cameron 1989) and offshore (Barrie 1988).

5.2 Exploration History

Richfield Oil Corporation first began activity in the Queen Charlotte region in 1958 with an onshore drilling program of five wells on Graham Island, followed by marine seismic surveys in Hecate Strait. Between 1963 and 1967, Shell Canada conducted offshore seismic surveys and geological mapping. The results provided the impetus for a drilling program between 1967 and 1969, which resulted in fourteen wells being drilled. Minor shows of oil and gas were encountered in four of the eight wells drilled in the Queen Charlotte Basin (Figures A.21 and A.22).

The federal and provincial governments both imposed moratoria on oil and gas activities offshore BC in the early 1970s, initially related to concerns surrounding crude oil tanker traffic from the Alaskan oil fields to markets in the US, as well as to jurisdictional disputes between Canada and BC concerning the Strait of Georgia.

The moratoria have been reviewed a number of times during the last three decades and in the early 1980s various environmental evaluations and reviews were developed (Chevron Canada Resources Ltd. 1982; Planning and Assessment Branch (BC Ministry of Environment) 1983; Petro-Canada 1983; West Coast Offshore Exploration Environmental Assessment Panel 1986). A joint federal-provincial environmental assessment panel recommended in 1986 that exploration activity could take place subject to some 90 conditions (West Coast Offshore Exploration Environmental Assessment Panel 1986). In June 1987, federal and provincial governments issued a joint response to that panel report, accepting the intent of a majority of the recommendations and announced that exploration activities would proceed “in the near future” subject to the signing of an offshore management accord. However, in 1989, as a result of environmental concerns arising from oil tanker spills off BC and Alaska, and due to a

lack of development interest by industry, the two governments decided to extend the moratoria indefinitely.

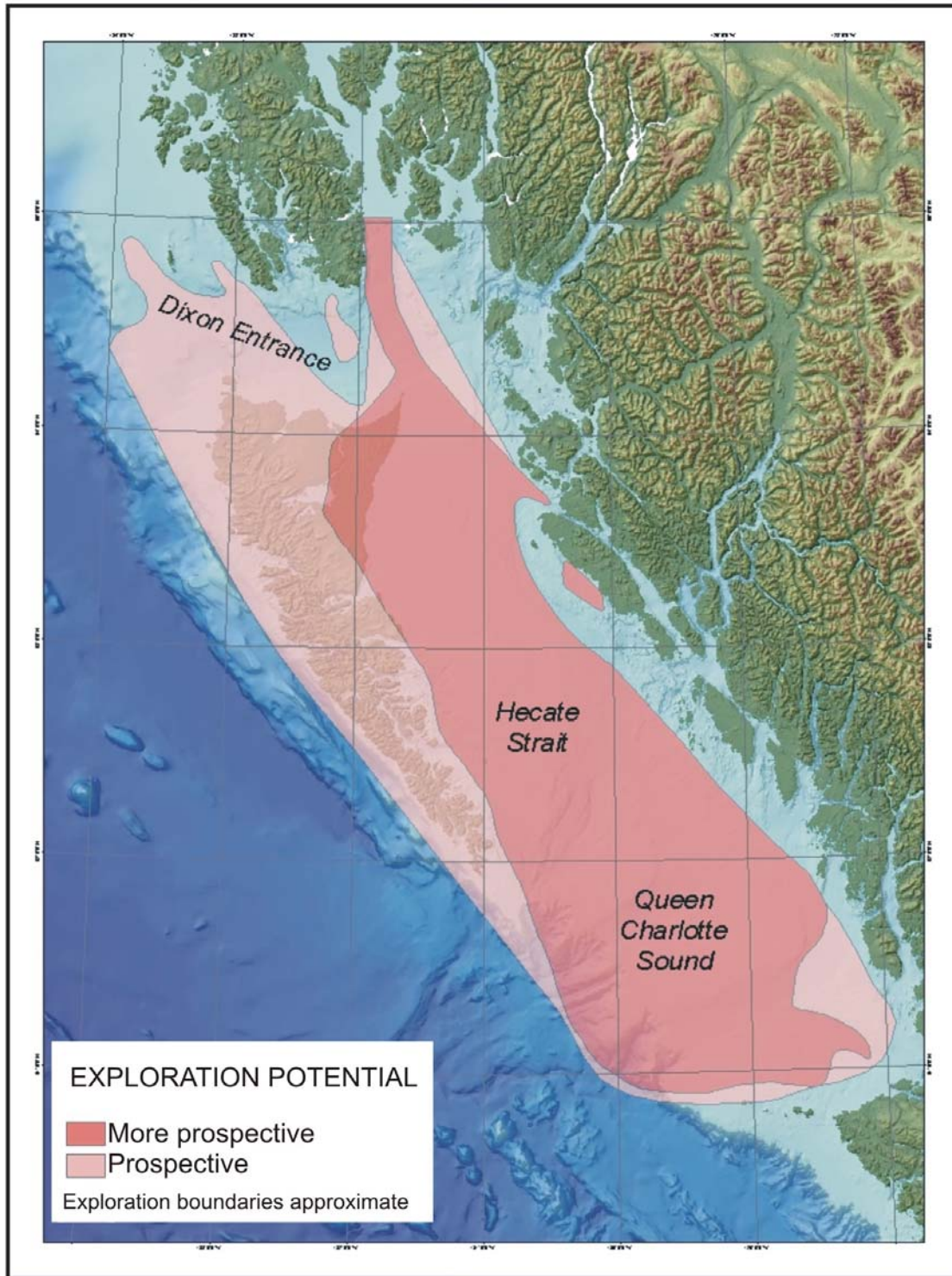


Figure A.22 Petroleum exploration potential in the Queen Charlotte Islands area.

In 2002, BC commissioned a scientific review of the moratorium and held stakeholder consultations. The conclusions indicated that there are no scientific or technical inadequacies that required a blanket continuation of the moratoria. After Cabinet consideration in December 2002, the Government of Canada initiated a three-part federal review process in March 2003 to identify any science gaps, and seek the views of the public and First Nations concerning whether or not to lift the moratorium for the Queen Charlotte Basin area. The Royal Society of Canada's independent science report prepared for Canada concluded in February 2004 that, provided an adequate regulatory regime is put in place, there are no science gaps that need to be filled before lifting the moratorium on oil and gas development (Hall *et al.* 2004). However, it noted that numerous science activities should be undertaken prior to exploration, development, and production activities.

Reviews of status of knowledge in the region related to offshore industrial development has been summarized in various reports in the last decade (Strong *et al.* 2002; Hall *et al.* 2004; Jacques Whitford Environment Ltd. 2001; Simon Fraser University 2000; Crawford *et al.* 2002; Jamieson and Davies 2004; Cretney *et al.* 2002a; 2002b; 2002c). A more detailed chronology of offshore oil and gas activity can be found on the BC Ministry of Energy and Mines web site, including more recent results (<http://www.offshoreoilandgas.gov.bc.ca/>).

5.3 Natural Gas Hydrates

Gas hydrates are ice-like substances (called clathrates) composed of molecules of natural gas trapped within the crystalline structure of frozen water. Methane hydrate is thought to be the most common in nature. They can form in areas of deep permafrost and such formations are found in the Canadian Arctic (Hyndman and Dallimore 2001). They can also form in ocean sediments where bottom temperatures are cold, depths are greater than 400 m, and there is a source of natural gas. In subduction zones, the sedimentary section is scraped off the subducting plate, creating an accretionary prism, and this is the case along the Vancouver Island margin. As the accretionary prism builds, porosity decreases rapidly with depth, causing methane rich pore fluid to be expelled and percolate upwards into the hydrate stability field, forming significant gas hydrate deposits (Hyndman and Davis 1992; Hyndman *et al.* 2001; Spence *et al.* 2000). Deposits may also exist further north, within the PNCIMA continental slope, but this has not been confirmed. The majority of the continental shelf is thought to be too shallow for gas hydrates to form.

Gas hydrates are significant for three reasons. First, natural gas is a fairly clean energy source and gas hydrates are thought to be very abundant worldwide. Furthermore, the clathrate structure is very efficient at storing the gas as one volume of gas hydrate will produce over 160 volumes of methane gas. Second, methane is a strong greenhouse gas and gas hydrates are a significant methane sink, so that the formation or melting/dissociation of gas hydrates have large climate implications. Third, the gas hydrates can be a seafloor hazard either due to shallow gas release or by contributing to seafloor instability (Hyndman and Dallimore 2001).

5.4 Offshore Aggregate Resources

More than 6.3×10^6 dry metric tonnes of sand and gravel aggregate has been mined from the nearshore waters of the basin near Prince Rupert since 1956 (Good 2004). This aggregate production was undertaken from some 17 Provincial lease blocks starting in 1956 and ending in 1997. The majority of the production was undertaken at one site where a tombolo near Metlakatla was completely removed. This production was largely unregulated and no environmental monitoring was undertaken. Construction aggregate is currently trucked in from the interior of the mainland, or obtained by small, local blasting and crushing operations. For any large-scale project within the basin, such as oil and gas production platforms, aggregate supplied by either of these options would be costly and logistically problematic, especially relative to barge transport of locally dredged material.

5.5 Marine Placer Mineral Deposits

Placers gold have been exploited in the intertidal and supralittoral zone on Graham Island for more than a century (Mandy 1934). In addition to coastal placers, shelf placer deposits of titanium rich sands are known to exist (Barrie *et al.* 1988). There is thus significant potential for marine placer resources to occur within the PNCIMA region.

5.6 Terrestrial Mineral Potential

A detailed review of the terrestrial mining activity in PNCIMA watersheds can be found in the PNCIMA Marine Use Analysis. Information on contaminant issues related to mining can be found in Haggarty *et al.* (2003).

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7.0 GLOSSARY

Accreted – The process of adding crustal blocks to continental land masses. Accreted terranes are those that become attached to a continent (e.g., western North America) as a result of tectonic processes.

Accretionary prism – Accretionary prisms grow at subduction zones, where sediments are scraped off, bulldozer-fashion, near the trench, or by underplating of subducted sediments and oceanic crust along the shallow parts of the subduction zone.

Clathrates – A clathrate or clathrate compound is a chemical substance consisting of a lattice of one type of molecule trapping and containing a second type of molecule. In the case of gas hydrate water molecules encloses a trapped gas molecule.

Eustatic – Pertaining to worldwide changes in sea level that affect all oceans, caused in the last few million years by the addition and removal of water from continental glaciers and ice caps.

Fluvial – Produced by the action of a stream or a river.

Grabens – An elongate relatively depressed crustal block that is bounded by faults on its long sides.

Isostatic – The condition of equilibrium, comparable to floating, of the units of the lithosphere above the asthenosphere.

Lithology – The physical character of a rock.

Littoral – Pertaining to the depth zone between high water and low water.

Paleoseismic – Pertaining to earthquakes of the geologic past.

Piedmont lobe – A thick continuous ice mass at the base of a mountain range.

Refugia – An isolated area that underwent little environmental change permitting a fauna or flora to persist locally long after it had been exterminated elsewhere.

Subducted – The process of one lithospheric plate descending beneath another.

Terranes – A terrane is a crustal block or fragment that preserves a distinctive geologic history that is different from the surrounding areas and that is usually bounded by faults.

Tombolo – A sand or gravel bar that connects an island with the mainland or with another island.

Transpression(al) Crustal – Deformation in zones of oblique compression that combines the two elements of strike slip and compression.

Transtensional Crustal – Deformation in zones that combines the two elements of extension and strike slip motion.

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