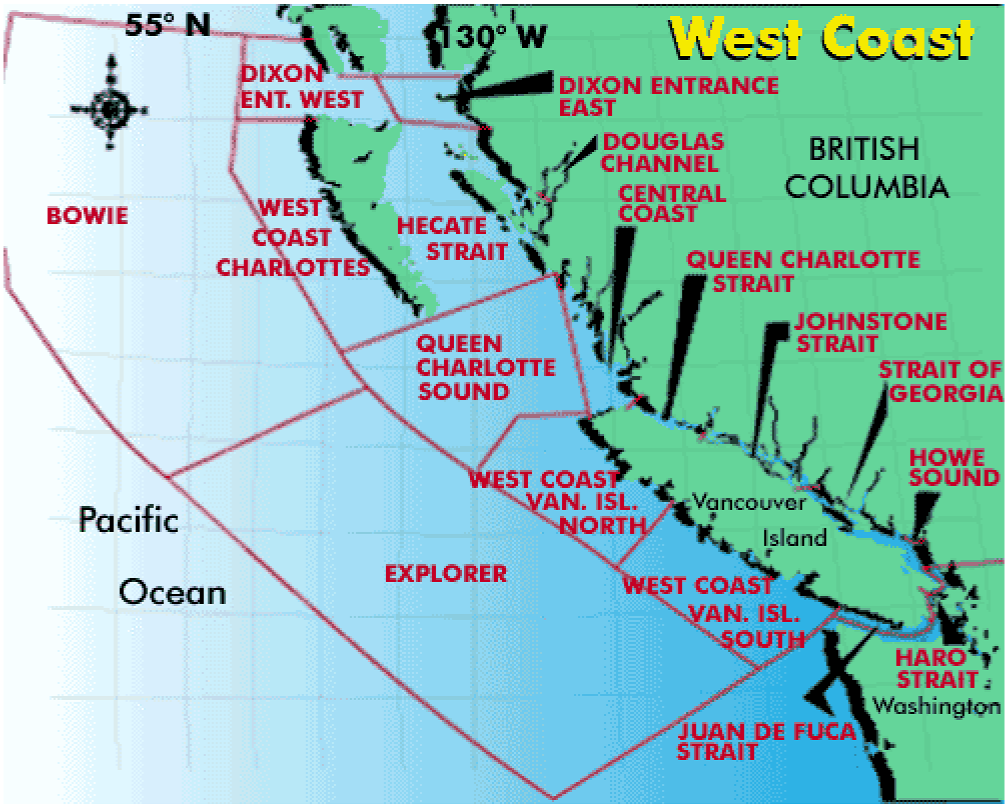

Figure 4.6 Weather forecast areas for British Columbia marine waters.

Forecast:

<u>Storm warning continued.</u>

Winds northeasterly 5 to 15 knots veering to southeast 20 this evening and rising gales 35 overnight. Winds rising to southeast gales 40 to storm force 50 Monday morning then easing to southerly 25 late Monday afternoon. Cloudy. Rain Monday. Seas near one metre building to 2 to 3 metres tonight and to 4 to 6 metres Monday morning. Outlook. Strong to gale force southerlies veering to strong westerly.

In addition to the regularly-scheduled marine forecasts, special marine weather warnings or weather advisories are issued as required:

STORM WARNING

STORM WARNING ISSUED FOR THE COASTAL WATERS OF BRITISH COLUMBIA BY THE PACIFIC WEATHER CENTRE OF ENVIRONMENT CANADA AT 8:49 PM PDT SUNDAY 14 OCTOBER 2001.

STORM WARNING ISSUED FOR BOWIE.

A 977 MILLIBAR LOW WILL MOVE ACROSS THE WESTERN SECTIONS OF THE BOWIE REGION ON MONDAY. WESTERLY STORM FORCE WINDS OF 50 TO 55 KNOTS ARE EXPECTED TO DEVELOP LATE MONDAY AFTERNOON AND EVENING AFTER LOW HAS PASSED.

FURTHER DETAILS FOLLOW IN THE NEXT REGULAR MARINE FORECAST AT 9:30 PM PDT.

The marine forecast desk is primarily served by a network of marine weather reporting stations and buoys (Figure 4.5)*. The stations report their parameters* (Table 4.2) *via satellite on an one hour basis, with observations being distributed to the AES observation network for application in numerical forecasts and as guidance information for the marine forecast desk.*

Marine observations (e.g., wind and sea state) are also reported to the observation network by ships of opportunity traveling through the region. These observations are rarely continuous for more than a few days and the geographic areas that they cover along the coast are somewhat random. Wind and wave observations from ships of opportunity are less accurate than buoy measurements, and are used in a qualitative manner by the forecast desk. However, ships of opportunity do report accurate measurements of atmospheric pressure; these pressure readings serve an important role as early-warning indicators for "marine bomb" events. Observations from ships of opportunity are reported every 6 hours.

Wind forecasts are prepared by Canadian Meteorological Centre (CMC) in Montreal using a numerical wind-prediction model *driven by the network of observations and surface analysis charts. Surface winds are supplied to* a *numerical wave forecasting computer model at CMC which is run twice a day and provides forecasts up to 48 hours. The* wave-forecasting *model uses a coarse grid with resolution on the order of 80 to 100 km.* This grid spacing has been found to be too coarse to fully resolve wave conditions during intense storm events.

The CMC forecast information is used as guidance by the marine forecast desk to produce their own subjective forecasts. Typically, the marine forecaster will modify the CMC forecasts based upon the specific marine regions, the latest observations, and their wave forecasting experience. Thus, the forecasting procedure represents a combination of data-driven numerical modelling coupled with interpretation and adjustment by experienced meteorologists.

In the early 1990's the forecast unit followed a "marine bomb" checklist to minimize the chance of these weather systems developing unnoticed. However, shortly after, the official *checklist was eliminated: the sophistication of the numerical forecast models and the increased experience of the forecasters made this task unnecessary. Weather system information is now well managed and rarely does a storm go undetected.*

Weather forecasts are currently verified through comparison with observed winds at two stations in the West Coast Vancouver Island North forecast area (Figure 4.6): Sartine Island and Solander Island. A statistically-rigorous procedure is used to assess forecast accuracy, with results reported for each month of the year. *The marine forecast unit indicates that it can adequately predict gale force and stronger events with a six hour or better notice time. Existing wave forecasts are believed to be accurate to within 0.5 to 1.0 m.*

Additional forecasting tools at the disposal of the marine forecasting desk include the Forecast Production Assistant, also known as the Pacific Wave Forecasting System (PWF). *The* PWF *includes an embedded wave model and allows the forecaster to adjust surface pressures as input to the model to allow better wind forecasts and more accurate hindcasts for specific forecast areas of interest. Generally, this is a tool that would be applied* in hindcast mode *for specific customers (e.g. offshore operators, or ships with specific vessel routing requirements) and is not used for* routine weather forecasts.

The marine forecast unit maintains good cooperative working relationships with the United States Weather Centre offices in Juneau, Alaska which results in shared information and mutual benefit to the forecast user communities along the British Columbia coast.

4.5 Gas Hydrates

Gas hydrates are solid forms of the commonly occurring gases in offshore sediments. Marine gas hydrates form in locations where the temperature and pressure regimes are sufficient to maintain the solid phase; on the western Canadian continental margin, hydrates are found below a water depth of approximately 800 m (David Mosher, pers. comm.). Gas hydrates are relatively abundant in offshore areas, having been retrieved by bottom draggers on numerous occasions.

Hydrates are typically identified on seismic profiles as bottom-simulating reflectors (BSRs). BSRs are evident on about half of the mid-continental slope; extensive research was conducted on one hydrate deposit through Leg 146 of the Ocean Drilling Program (Hyndman et al. 2001).

Gas hydrates pose some hazards to exploratory drilling operations. The drilling itself may cause dissociation of the solid phase, increasing the free gas content in the bottom sediments and potentially leading to decreases in sediment strength and slope stability. However, gas hydrates are a common occurrence in other waters where hydrocarbon exploration and development activities are ongoing, and there exists considerable experience in dealing with the potential hazards. In addition to posing a potential hazard to drilling activities, hydrates are seen as an undeveloped resource to be exploited in the future as the appropriate technologies are developed.

4.6 Faulting and Earthquakes

The area around the Queen Charlotte Islands, Dixon Entrance, Hecate Strait and Queen Charlotte Sound is known to be one of the most seismically active areas of the world. However, as discussed later in

Section 5, many existing offshore oil and gas developments have been designed for similar seismic activity.

Among the most important seismo-tectonic features in this area is the northwest trending Queen Charlotte Fault (QCF) that forms the transform boundary between the North American Plate to the east and the Pacific Plate to the west (Figure 4.7). The QCF lies within 10 to 20 km (6 to 12 miles) off the west coast of the Queen Charlottes Island and transects the northern portion of the Petro-Canada lease area. Several large earthquakes have been ascribed to the movements along the QCF with a 1949 earthquake of Magnitude 8.1 (M8.1) and a few other events exceeding M7. The 1949 M8.1 event was triggered by a fault break several hundred kilometres long and resulted in a fault displacement of about 8 m (26 feet). The most recent one of these events was the M7.4 earthquake that occurred in 1974 near the southern tip of the Queen Charlottes Islands. Another M8.2 event occurred on the northward extension of the QCF along a segment known as the Fairweather Fault in Yakutat Bay, Alaska in 1899.

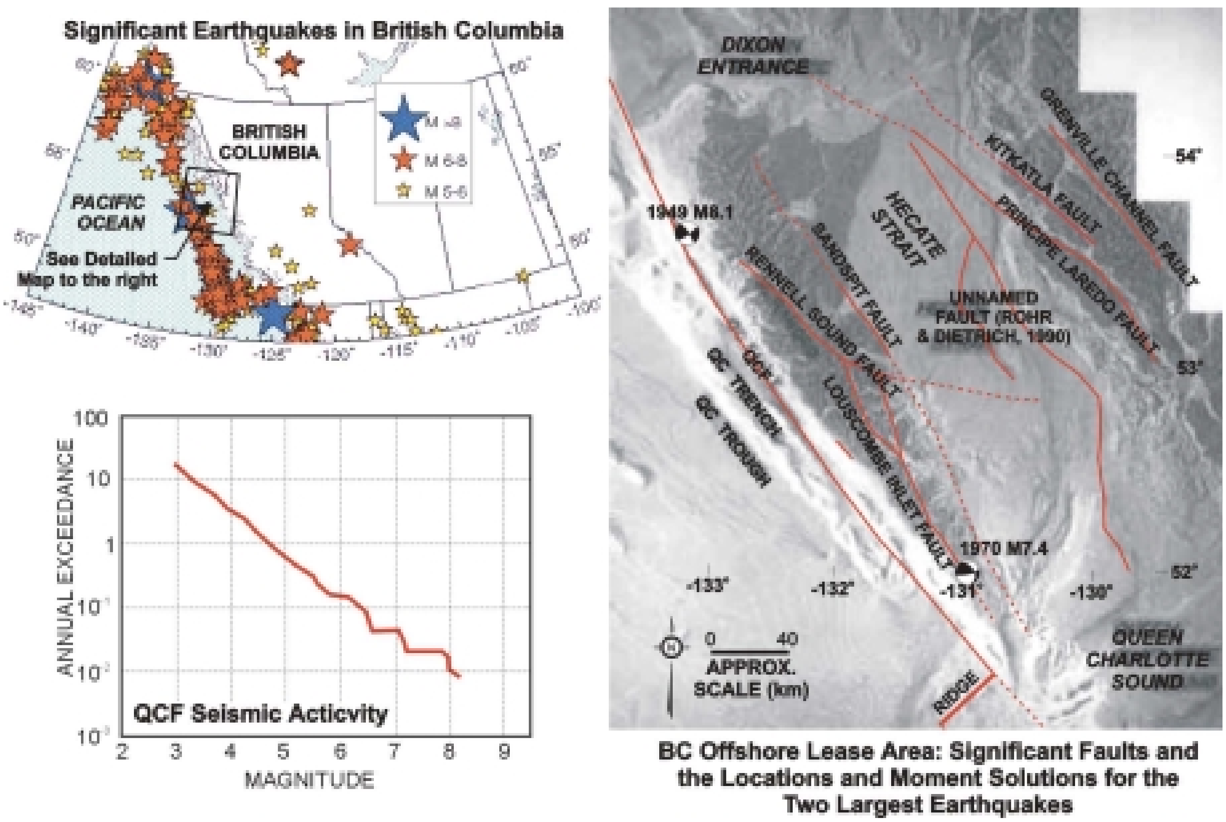

Figure 4.7 Seismicity and Faulting around the Queen Charlotte Islands

The Yakutat Bay earthquake was triggered by a several hundred kilometres long fault break and resulted in a displacement of 15 m (49 feet). Such an earthquake is expected to occur within 3 to 15 km (2 to 9 miles) below seafloor. Several other shallow, northwest trending faults cross the Queen Charlottes Islands. Some of these faults have been identified from the seismic data obtained during the earlier offshore oil and gas Exploration and Production (E&P) activities in this area and the geophysical survey of the Geological Survey of Canada (Rohr and Dietrich 1990; 1991). From west to east, most notable ones are the Rennel Sound Fault and the Sandspit Fault. The Rennel Sound Fault follows the centre of Moresby Island. The Sandspit Fault begins from the northeastern portion of Moresby Island south of Sandspit and appears to continue to north central Graham Island. It has been hypothesized that the cluster of seismic activity in the north central Graham Island is ascribable to the Sandspit Fault, although it is possible that these activities are due to deeper faults that are yet to be identified. Another fault has been proposed in east central Hecate Strait based on seismic data (Rohr and Dietrich 1990), the northern portion which also appears to be seismically (earthquake) active. The historical earthquake data and the length of fault trace indicate that seismicity along the QCF is capable of generating an earthquake between M8.5 and M9.0 (see, e.g., Slemmons and McKinney 1977). M7 earthquakes are likely to occur within 3 to 15 km (2 to 9 miles) below seafloor along other active faults west of QCF.

When assessing the potential impact of faults and fault movements on the location and design of offshore oil and gas facilities, it is necessary to estimate the relative age of fault or time since the last apparent movements or displacements along the fault. For designing structures it is considered appropriate to assess the likelihood of movements since the last ice age, i.e., within the past 12,000 years. Faults that could have moved since then are deemed potentially active. As discussed in later sections, investigations would be undertaken to identify and avoid the locations of potentially active faults for locating offshore oil and gas facilities.

4.6.1 Accelerations and Ground Motion

The results of probabilistic seismic hazard analysis presented by CGS (1992) indicates that the 1 in 475 year earthquake peak horizontal acceleration (PHA) west of central Hecate Strait and north central Graham Island is between 0.32 and 0.4 times the acceleration due to gravity (g). The corresponding peak ground velocity (PGV) is between 0.32 and 0.4 m/s (12.6 to 15.7 foot per second). Further east, the PHA for 1 in 475 year earthquake decreases to 0.12g along the eastern shoreline of Hecate Strait and the corresponding PGV is 0.24 m/s (9.4 foot per second).

The historical seismicity in this area was re-examined in connection with the recent proposal of changing the seismic design basis in the Canadian National Building Code from 1 in 475 earthquake to 1 in 2,500 year (Adams, Halchuk and Weichart 2000). These results indicate that in the onshore areas of the Queen Charlotte Island and its immediate offshore vicinity, a 1 in 2,500 year event would lead to a PGA between 0.8g and 1.2g. In north central Hecate Strait the corresponding PGA is between 0.4g and 0.6g, while in the remainder of the lease areas are likely to experience a PGA between 0.16g to 0.40g.

The commonly used code of practice for designing fixed offshore platforms, API RP 2A, has in-built earthquake design procedures that account for the level of ground motion in US offshore areas. These procedures can be readily modified to account for the anticipated ground motions in British Columbia offshore.

4.6.2 Tsunamis

Tsunamis or sea waves are generated by sudden vertical motion of the seafloor resulting from an earthquake or a submarine landslide. The seismo-tectonic regime in the vicinity of Dixon Entrance, Hecate Strait and Queen Charlotte Sound is dominated by strike-slip mechanism and is thus not perceived as particularly tsunamigenic. However, the seismic activities are likely to cause landslides, which in turn may trigger tsunamis. Tsunamis generated by distant subduction earthquakes may also affect this area. Tsunami waves travel at velocities of several hundred kilometres per hour and affect areas several thousand kilometres away. The tsunamis from the Aleutian Islands are therefore likely to reach the areas off the Queen Charlotte Islands within minutes after the trigger. These events are therefore also of concern in the design of offshore oil and gas facilities around the Queen Charlotte Islands. Areas most vulnerable are adjacent to steep onshore bluffs, submarine slopes, and enclosed basins. Several tsunamis have been reported in the coastal areas of British Columbia and Alaska Panhandle. Most significant among these was the tsunami generated during a 1958 earthquake on the Fairweather Fault. A large landslide triggered during this event crashed into Lituya Bay generating 30 m (100 feet) waves that stripped trees to 520 m (1700 feet) elevation on the opposite shoreline. A non earthquake-related submarine landslide destroyed a part of Skagway Harbour in Alaska in November 1994.

Satake (2001) reports an analytical study of tsunami in the Pacific Rim triggered by a large landslide in the Hawaiian Islands and estimated that the tsunami height could be 30 m (100 feet) in the western margins of Dixon Entrance and Queen Charlotte Sound. Lynett *et al.* (2001) also proposed a numerical model for tsunamis. The site-specific tsunami-related design parameters including wave heights and run-up can be estimated for the oil and gas developments in British Columbia offshore lease areas following such procedures. These parameters should then be used in structural design and risk management of offshore oil and gas facilities.

4.7 Fault Movement, Slope Stability and Liquefaction Potential

Among the significant geotechnical issues for the design of offshore oil and gas facilities are fault movement, submarine slope stability and liquefaction potential. For managing these risks, the areas of potential instability are first identified from shallow geophysical, bathymetric and oceanographic surveys so that the facilities can be located in lower risk areas. It is difficult to estimate ground movements for fault break, slope instability and liquefaction using rigorous analytical procedures. Worldwide experience and empirical methods are usually relied on for estimating the effects of these instabilities. For instance, a conservative (upper bound) magnitude of fault movement can be estimated using empirical relationships based on observations (e.g., Wells and Coppersmith 1994). The ground movements due to potential slope instability and liquefaction are similarly estimated for a trigger (e.g., an earthquake) with a large return period (typically 1,000 year) using soil strengths from geotechnical testing and following empirical procedures such as Hynes-Griffin and Franklin (1984), and Youd and Idriss (1996). Where appropriate, more sophisticated finite element computer models can be used to predict soil movements and the impact on facilities. The offshore oil and gas facilities should be designed for these low-likelihood ground movements.

Shallow faults and the extent of deformation of unlithified seafloor sediments are often identifiable from careful interpretation of high resolution seismic survey data. In certain conditions, the deformation of the sediments overlying shallow faults is inferred to be due to fault movements or creep and the underlying fault is deemed as potentially active. Bathymetric surveys can look for topographic patterns associated with slope instability. Such signatures of slope instability include toe-bulge, hummocky seafloor and talus heaps near the foot of steep submarine slopes. The presence of gas in seafloor sediments can often be identified from the high resolution seismic survey because gassy sediments absorb a significant portion of the seismic energy and wipes out the reflections from underlying layers. In some areas of British Columbia offshore gassy sediments are known to be associated with slope instability.

After completion of a detailed geophysical survey, areas of potential soil instability can be further investigated using geotechnical in-situ testing tools and sampling procedures. These investigations typically involve piezocone penetration testing (CPT), pressuremeter testing (PMT) and drilling and soil sampling. Laboratory tests are carried out on recovered samples to estimate soil strength and other engineering properties. The objective of the geotechnical investigation is to estimate the shear strength of the soil, based on which the possible soil stability can be assessed. These issues are discussed in more detail in Section 5.

4.8 Summary

In summary, the northern waters of British Columbia present a complex physical environment, with highly variable bathymetry, strong winds and currents, and high waves during storm events. The region is also one of high seismic activity, with the associated risk of slope failure and tsunami generation. Conversely, the significant risk to offshore facilities posed by icebergs on the Grand Banks of Newfoundland is not found on the west coast of Canada.

The extent of our knowledge of the physical characteristics of the west coast marine environment varies, depending on the physical aspect under consideration, and is highly dependent on the extent of previous regional data collection efforts. In general, our current state of knowledge regarding the physical environment of these waters has improved significantly since the 1986 report of the WCOEEAP.

Although the physical characteristics of the northern waters are relatively complex and there are areas where our knowledge base needs improvement, the technologies to do so are readily available and need only the dedication of sufficient resources to the task. In other jurisdictions such as the east coast of Canada, the collection of the required data has proceeded through the combined efforts of government and industry as offshore activities proceeded from the planning through the implementation stages.

The physical conditions under which offshore hydrocarbon exploration, development and production activities occur impact engineering designs, operational procedures and environmental impacts associated with any contaminant releases to the marine environment. Uncertainties in the physical parameters discussed in this section can be dealt with through standard approaches such as increased factors of safety included in engineering designs and operational procedures, while environmental concerns can be reduced through the incorporation of additional spill prevention measures into offshore equipment. The net effect of high uncertainties in the physical conditions under which offshore activities are to occur is to increase the cost of offshore activities and reduce the economic feasibility of a given project, rather than to limit the technical feasibility of offshore exploration.