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ENVIRONMENTAL FACTORS

CHAPTER THREE ENVIRONMENTAL FACTORS

Man and the sea are age-old adversaries; man covets the riches of the oceans but the oceans are jealous guardians of their wealth. For centuries the Northwest Atlantic has been harvested for its live bounty; now man seeks a newer treasure – hydrocarbons – the fossilized remains of the ocean's ancient life. Those who lead this uncharted venture are equipped with the most sophisticated means yet devised to combat the forces of wind and wave. But they have had to learn the lessons of our seafaring past: the sea cannot be conquered; it must be endured.

Those who prospect for oil and gas are faced with quandaries unknown to earlier men of the sea. Fisherfolk traditionally build the sturdiest craft within their means to launch upon the ocean. That these vessels may not be sturdy enough is known to all; such is the tariff exacted by the sea from those who would harvest its waters. Today's technology promises something more, something safer. The huge drilling rigs come close to achieving this goal; the effects of the ocean's swell are restrained; the elements shut out by a carapace of steel, and the sheer mass of the structure offers its tenants a land-like security. But even these hybrids of marine and industrial technology may not be sturdy enough. One must wonder how a technology that protects man as he ventures to the moon and back cannot protect him from his ancient enemy, the sea. The answer lies not in logic, but in the more modern science of economics. Drilling rigs could indeed be fabricated to resist any environmental force known to man; but so to construct them would render the venture that they are designed to service economically unfeasible. Thus the sea continues to claim its toll in lives, and those who seek to diminish that toll recognize that any progress that they make will merely be relative to the higher costs that might have been.

The offshore oil industry, like other modern enterprises, counters the risk to its work force by promising protection. If there is any likelihood of a drilling rig failing an environmental test, activities cease and man withdraws to the land. As sea ice and icebergs invade the exploration areas off the East Coast of Canada each year, rigs and fishing boats alike retreat to safer quarters. As hurricanes are forecast to sweep through the Gulf of Mexico or typhoons through the China Sea, crews are evacuated and those rigs that cannot be moved are left to the mercy of the storm. These strategies involve high costs in lost drilling time. Yet the total figure is much lower than the cost of providing drilling fleets that are so designed and so constructed that they will survive the harshest extremes that the environment can muster. From the perspective of industry, then, present withdrawal and evacuation procedures form a responsible compromise between the often conflicting ideals of human safety and economic feasibility.

That this compromise works reasonably well is evidenced by the statistics. Although many MODU accidents have been attributed to environmental factors, relatively few of them have resulted in lost lives; threatening conditions were generally forecast well enough in advance to enable the crew to be brought to safety. There are two key criteria which control the success or failure of this strategy. First, industry must know with precision what environmental conditions are to be anticipated at a given drilling location. Only then can rigs be designed to surmount these forces and environmental limitations be established for the evacuation of the rig. Second, forecasting procedures must be so developed that accurate and timely warning is afforded of those approaching extremes which may warrant precautionary action. These key criteria are accommodated to varying degrees in different offshore regions of the world. Some areas of exploitation, like the North Sea, have been subjected to years of careful environmental mapping and the data needed for the analysis and estimation of normal and extreme conditions are relatively well documented and readily available. The East Coast of Canada is a more isolated area that is new to offshore activity; there, data are comparatively sparse and not always reliable. It is relatively simple to forecast dramatic departures from normally placid climatic conditions, for example a hurricane in the Gulf of Mexico; it is virtually impossible to predict accurately the path or velocity of an isolated iceberg in the erratic currents of the Northwest Atlantic.

Few areas in the world represent as challenging a drilling terrain as the continental shelf off eastern Canada. Nowhere else are permutations and combinations of wind, waves, fog, and ice as perilous and as unpredictable as in that vast and varied expanse of ocean. Environmental extremes on the Grand Banks generally include wave heights of 30 metres, winds of 100 knots, currents of 2 metres per second, frequent sea ice and icebergs, and heavy fog which limits visibility to below 1 kilometre as much as 45 percent of the time. These conditions influence both the design of exploration equipment destined for use in the area and the daily operations of the drilling rigs, supply vessels and helicopters that work at the drilling sites.

Industry's strategy of protecting the offshore work force by vigilant forecasting and timely evacuation faces a number of caveats off the East Coast of Canada. Some environmental factors in this region are imperfectly understood, and some predictive techniques inadequately proven. Even if rigs are designed such that they successfully resist the direct onslaught of sea and wind, the very frequency of adverse weather poses a myriad of problems. High winds and seas and heavy icing loads leave little room for error in the performance of men and equipment. A minor miscalculation or oversight in design, construction or operation which would prove inconsequential under normal circumstances, may be forced into the open to form the initial link in a chain of events that culminates in disaster. Such a chain was forged the night the *Ocean Ranger* was lost; although the storm did not sink the rig, it would not have sunk without the storm.

Should an offshore catastrophe occur, for any reason and in any location, environmental conditions will often determine how many lives are saved or lost. The eastern Canadian offshore again poses special problems. Even when warning is given of approaching ice or of a severe storm, helicopters may be unable to reach those on board a drilling rig because of fog, high winds, or icing, and a MODU may be unable to move off location if seas are too rough to permit anchor-handling or towing. Should the emergency be precipitated by a blowout or collision, there would rarely be enough lead time for helicopters to cover the considerable distance from shore. In each of these events, the only avenue of escape would be into the ocean. Estimates of the chances of a successful evacuation by sea with existing lifesaving equipment decline from 82 percent in calm weather, to 10 percent in severe weather.[1] With the frequency of severe conditions off the coast of Newfoundland and the dire

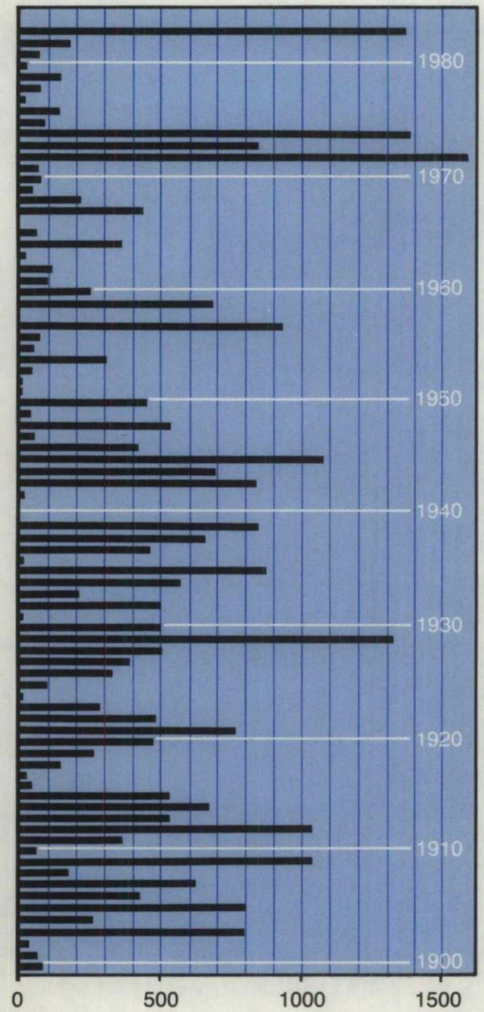
[1]A joint study project by the U.K. Department of Energy and the U.K. Offshore Operators Association. Calm weather is defined as up to Force 3 and severe weather, Force 8 and above.

3.1 Collisions with ice still pose a threat to conventional ships in spite of the availability of radar and ice reports.

precedent of the *Ocean Ranger's* evacuation, this aspect of the environmental problem may well prove the most intractable and potentially the most tragic.

Those concerned for the protection of workers off Canada's eastern shores have raised questions regarding present levels of environmental information and existing methods of hazard prediction. The lessons of the *Ocean Ranger* disaster, the widely recognized inadequacy of contemporary evacuation systems, and the prospect of new problems as activity expands all warn against accepting a complacent assurance that all is well. As is man's way, it takes a tragedy of catastrophic proportions to effect significant change in society's methods of protecting its members. The loss of the supposedly unsinkable *Titanic* to an iceberg, not far from where drilling operations are now in progress on the Grand Banks, proved conclusively that icebergs were, indeed, a threat in the Northwest Atlantic shipping lanes and that lifesaving equipment was, indeed, inadequate. It is hoped that other environmental threats in this harsh milieu need not exert the same burden of proof before man admits that they, too, pose a problem, and that the designation "unsinkable" remains a relative and largely utopian term.

Neither those who design and build MODUs for the eastern Canadian offshore nor those who operate and maintain them can perform their functions effectively without access to a diverse array of environmental data (Appendix C, Item 5). Information on ice, waves and wind are fundamental requisites; so too are data on how these complex elements interact and the extremes that they may attain. For centuries man has perceived a need for structures that would permit him to travel freely on the sea's surface and harvest its depths despite the presence of ice. Never has that need been more strongly in evidence than in recent years off the East Coast of Canada. Offshore operations may proceed or halt for weeks or months in response to the changing movements of pack ice and icebergs.



3.2 The yearly variation in the number of icebergs which complete the journey from the glaciers of Greenland to cross latitude 48°N. In recent years, the development of synthetic aperture radar and side-looking airborne radar has radically improved the effectiveness of ice reconnaissance programs. In 1984, the International Ice Patrol made 78 flights and 49 percent of the icebergs detected were attributed to the use of airborne radar. During that year 2,202 icebergs were estimated to have crossed 48°N.

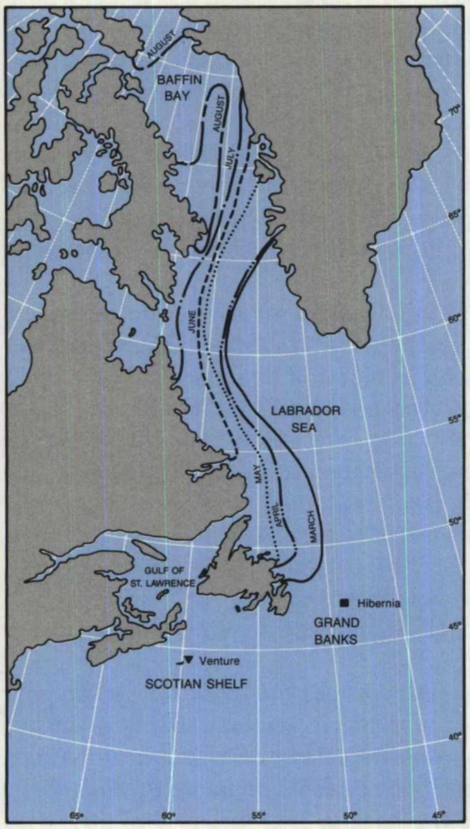
Pack ice or sea ice is formed by the freezing of the sea's surface layer and is found year round in the northern areas of Baffin Bay and Lancaster Sound. Although first-year ice rarely grows to more than two metres in thickness through the process of freezing, considerably thicker floes are built up by the continuous relative motion of wind and currents which generates both rafting and ridging. Rafting results when one ice sheet overrides another, and ridging forms when a line of broken ice is forced up or down because of pressure, and the blocks become frozen together. These processes produce the characteristic rough and ridged topography of sea ice.

As this ice ages, the brine is leached out and the ice becomes stronger. During the winter the Arctic pack expands and drifts southward until by late winter or early spring it reaches its maximum coverage, extending to the Grand Banks off the coast of Newfoundland. As this rugged, sometimes multi-year ice moves south, it breaks and scatters through packs of newer and locally formed ice. The sea ice that hovers north of the drill sites off Labrador in the fall and extends into the Hibernia area in the winter usually consists of Labrador ice interspersed with isolated Arctic floes and remnants of icebergs. Sea ice also forms in the Gulf of St. Lawrence, but this ice is not as thick as the Labrador pack and includes neither Arctic ice nor icebergs. In most years this pack extends over the northern Scotian Shelf but it has not yet been reported as far south as Sable Island.

Movement of pack ice off the East Coast of Newfoundland varies with winds and tides, but it can be surprisingly rapid, particularly when driven by the Labrador current. Reports of pack ice velocities averaged over a week have reached 40 kilometres per day at Hibernia and have exceeded 50 kilometres per day in the Avalon Channel. Pack ice moving at this rate can sweep a vessel along in its path and force a drilling rig off location. Since no drilling rigs and very few supply vessels operating in this area are Ice Class, these hazards, coupled with the danger of puncture by pieces of tough, Arctic ice, dictate the prudent practice of ceasing activity as sea ice encroaches.

Another sea-borne hazard in the Northwest Atlantic is the iceberg, the mariner's legendary foe. Calved from the glaciers of Greenland, these leviathans of the north may weigh many millions of tonnes. Their journey south is a slow progression subject to the vagaries of wind and current and the undulations of the sea floor. Relatively few icebergs escape the confines of the fiords where they were born, and even fewer survive the one- to three-year journey to the warmer, lower latitudes. Although the southern limits of their sightings, the Grand Banks of Newfoundland, have known ice-free seasons, in other years over 2,000 icebergs have moved south of 48° north latitude.

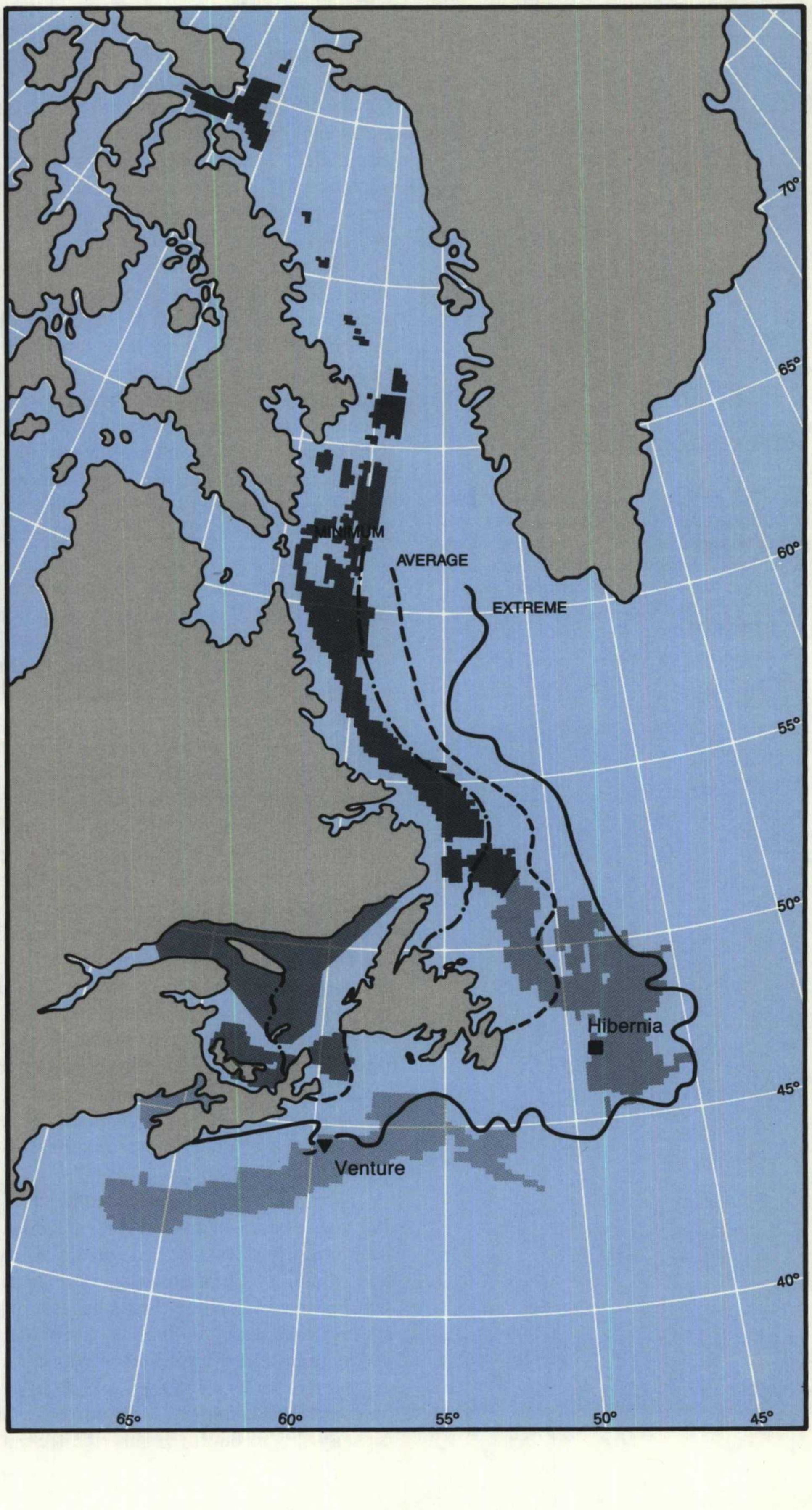
Iceberg ice is harder than sea ice, partly because it derives from fresh water and partly because of the way it was formed. As E.J. Pratt described the iceberg in *The Titanic*, "pressure and glacial time had stratified / The berg to the consistency of flint." This hardness has long made the iceberg the most formidable environmental force in these waters. Large icebergs can generally be avoided; it is the smaller progeny that worsen the already complex operating conditions in eastern Canadian waters. As the iceberg journeys south, warming by sun and sea produces fractures which split the berg into fragments called "bergy bits" and "growlers". These offspring can be approximately but conveniently classified according to above-water dimensions and total mass. A bergy bit will look as large as a typical small house and weigh up to 7,000 tonnes; its smaller sibling, the growler, appears above water the size of a grand piano and will usually be under 200 tonnes in weight. When we are dealing with vistas as broad as the isolated drilling sites of the Northwest Atlantic and structures as massive as oil rigs, there are few environmental enemies to be feared as much as the diminutive, undetected growler, camouflaged amidst floes of softer sea ice, or borne at speed in storm-lashed waves, to crash with deadly impact against any obstacle in its path.

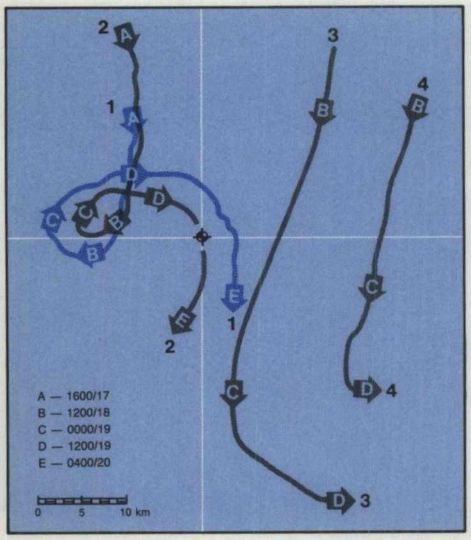


3.3 Pack ice, composed of Arctic ice and locally formed sea ice, poses particular problems for drilling operations on the Grand Banks. In the spring of 1985 pack ice and icebergs, driven by strong winds and the Labrador current, completely covered the Hibernia drilling area and resulted in the cessation of drilling for almost eight weeks.

Approximate drilling season:

- 3 months
- 3 to 5 months
- 8 months
- 8 to 12 months
- 12 months





3.4 The paths of four icebergs near a wellsite off the coast of Labrador illustrate the difficulties encountered in predicting iceberg trajectories. Although iceberg movement is predicted twelve hours in advance, an examination of 1,000 individual predictions revealed that about 70 percent of the forecasting errors exceeded four nautical miles.

Those exploring for oil and gas off the East Coast of Canada have addressed the challenge of icebergs by developing a system of "ice management" which is predicated on avoiding collision with ice. This approach is used in the ice-frequented waters off Labrador where dynamically positioned drill ships are employed for seasonal exploration. The strategy has been adapted for use further south in the Hibernia field where semisubmersible drilling rigs are used year-round. Because anchored MODUs take considerably longer to move off position than those dynamically positioned, it is essential that any ice in the vicinity of operations be detected and tracked at an early stage.

Industry's ice management program is built around a series of concentric alert zones which define the time it would take for the ice to reach the rig, and a corresponding series of actions or responses. The first recourse, if an iceberg is observed to be drifting towards a rig is to tow the berg. Accomplishing this feat in rough seas and high winds without the tow line slipping or the berg rolling over is always arduous and often impossible. Troublesome, too, is the herculean task of raising a rig's anchors if this first recourse fails and the rig is left with no option but to depart the drill site. Heavy seas and high winds make anchor-handling hazardous particularly if circumstances dictate that it be done quickly. The final resort, if environmental conditions are severe enough that anchors cannot be pulled and the iceberg is still approaching the rig, is to activate the quick-release mooring system which severs the anchor chains.

If an iceberg should escape detection and penetrate the inner alert zones surrounding a rig, if environmental conditions or time should preclude towing or anchor handling, if a mechanical problem should prevent the release of even one of the rig's eight to twelve anchor chains, then contingency plans can do no more; the fate of the rig is determined by the inexorable course of the iceberg. The likelihood of this series of events occurring is small but far from negligible. The likelihood of its occurring in weather conditions that prevent evacuation of the crew by helicopter or supply vessel is smaller yet, but, as history will testify, it is sufficient to invite serious reflection. In February of 1983, for example, the *West Venture* was drilling on the Hibernia field when storm conditions and approaching icebergs forced suspension of drilling. Helicopters could not fly because of freezing rain and poor visibility; anchors could not be pulled nor personnel transferred to supply vessels because of sixty-foot seas and eighty-knot winds. The quick-release mooring system had never been tested operationally and to activate it in storm conditions was judged less prudent than riding out the two-and-a-half day storm at anchor. Even had the anchor chains been released successfully, the rig was neither self-propelled nor capable of being taken under tow in the high seas, and would thus have drifted without control amidst the ice until the storm abated. Luck was with the *West Venture*; of the ten small icebergs and bergy bits in the immediate vicinity of the rig, none came closer than seven nautical miles. A considerably closer encounter with an iceberg was experienced by the *Bow Drill III* on the Grand Banks in April of 1985; unable to pull its last remaining anchor, or to severe the chain, the rig remained near the wellsite as the iceberg passed within one-half nautical mile.

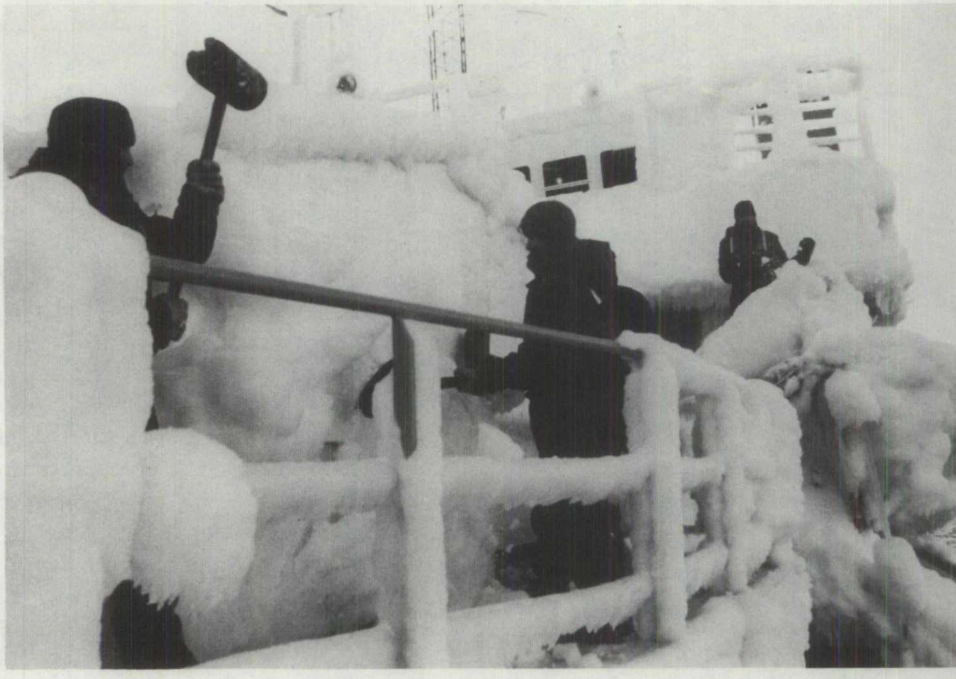
Initially, each operator conducted his own ice management program, but in 1983, as a result of the *West Venture* incident, a joint industry and government surveillance group was formed for the Hibernia area to pool resources, data and detection capability. A common operations centre co-ordinates information received from regular reconnaissance flights by government and industry aircraft, from ice observers on board each drilling rig, and from the International Ice Patrol. The degree of coverage provided by this observing network is thorough but not infallible. Icebergs are poor radar targets; they can often be seen with the naked eye before they show on conventional marine radar screens. The possibility exists that a growler or bergy bit may slip through the surveillance net, particularly at night, or when visibility is restricted by fog or heavy weather. Rough seas create "sea clutter" or interference on radar screens, masking the return from weak radar targets like growlers. By sea state 6, clutter extends far enough to reduce detection reliability for small targets to near zero. Research is underway to upgrade the capabilities for ice detection of both conventional ships' radar and sophisticated airborne-imaging radars.

When an iceberg approaches a drilling site, those in command are faced with a crucial task. They must determine whether the berg is on a collision course with the rig and, if so, whether it can be towed off that course by the supply vessels. This seemingly straightforward decision is charged with complexities. Methods in use today for predicting the path of icebergs cannot estimate berg movement beyond 12 hours' lead time and, even at this range, are not always dependable. This poor performance derives in large measure from the difficulties involved in estimating the direction and speed of the currents governing the berg's flow. These currents can be highly variable, even within a short distance, so much so that the net effect of the dominant current, its tidal component and the local wind can influence icebergs no more than five kilometres apart so that they travel in opposite directions. Measurements of the currents used for predicting an iceberg's course are generally taken at the site of the rig and not near the berg itself, a procedure which significantly affects the accuracy of the prediction. Advanced predictive models have been developed based on the previous trajectory of the iceberg; these show a slightly better performance record than the conventionally used methods. Other research is in progress to evaluate the feasibility of a model which measures the current within two kilometres of the actual iceberg by means of recently available acoustic current profilers.

In order to continue to operate safely among sea ice and icebergs, those involved in offshore exploration need to understand more clearly ice properties, ice behaviour and the chances and consequences of collision. Authorities at the National Research Council of Canada and the Norwegian Hydrodynamic Laboratories have specified their needs for new environmental data if they are to model the interactions between ice and man-made structures (Appendix C, Item 2). Much of this missing data involves measurements of the mechanical properties of sea ice and icebergs, including such parameters as strain rates and fracture resistance. This information will take years to accumulate and to apply in modelling, design and construction. There is also a need for more research and development in ice detection and in the prediction of iceberg movement. These tasks must be started now, if improvements are to be made in the efficiency and safety of drilling operations off the East Coast of Canada.

Icing is yet another environmental foe in northern climes. As super-cooled water droplets from sea spray, precipitation or fog strike frigid surfaces, the moisture freezes and forms an often impenetrable coating of ice. Icing is a common phenomenon off the East Coast of Canada as sub-zero winds blow sea spray from the tops of waves. The offshore supply vessels commonly used in this area are designed to carry a heavy icing load without losing stability, but many a conventional vessel has foundered or capsized under the weight of ice accumulated on its superstructure.

Drilling rigs are less vulnerable to sea spray icing than are conventional vessels; rigs tower above the waves and, as they are stationary, they generate no spray of their own. Although very few cases of serious rig icing have been reported in the eastern Canadian offshore, there is adequate evidence to warrant concern. In 1970 the drill rig *Sedneth* operating on the Scotian Shelf accumulated an estimated 200 tonnes of icing. At one stage the rate of ice loading increased the rig's draft by one foot per hour, bringing it close to its maximum allowable draft and preparations were made to dump drilling mud and cargo to compensate for the ice load when the accumulation ceased. Another example of severe icing occurred in Cook Inlet, Alaska; measurements on the semisubmersible *Ocean Bounty* were carried out in conditions that are environmentally possible over eastern Canadian waters. During this



3.5 Severe icing due to sea spray and freezing rain is a common phenomenon for vessels operating on the Grand Banks. Although icing may be less intense on drilling rigs due to their configuration and operation, there is no scientific basis upon which the probability of occurrence of extreme icing can be based. Several semisubmersibles constructed recently for operations in Arctic waters have incorporated de-icing systems to prevent the accumulation of ice.

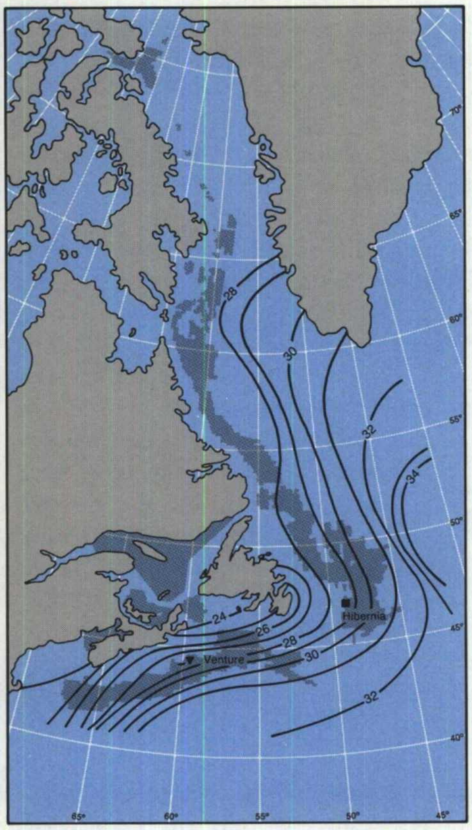
experiment, ice accumulation rates of from 5 to 25 centimetres per day were recorded, some in a zone as high as 30 metres above the sea surface. The total ice accumulation during a particularly severe period was estimated at 500 tonnes, enough to threaten the stability of the rig.

A more prevalent threat posed by icing is the danger to emergency equipment. Winches and release gear for lifeboats are affected by even moderate ice conditions and severe icing can make them inoperable. Helicopter operations are also susceptible to icing that is generated by mist-like particles of water in fog or cloud. This "rime" icing may restrict air intake or reduce lift by accumulating on rotor blades. Reports of rime icing frequently prevent or delay flights or force pilots to change altitude en route. During emergencies, these restrictions could prevent the timely arrival of rescue.

Current technological tools do not include the data needed to estimate reliably the likelihood of serious icing events offshore, to calculate accurately accumulation rates on fixed surfaces, particularly on the undersides of drilling rigs, or to develop vertical profiles of icing rates over water. These uncertainties pose problems for the rig designer and for operational safety offshore. Research into the physics and climatology of icing phenomena should be a priority for the meteorological community and the industry, and more accurate and useful methods of measuring and recording icing data should be sought.

Many a seaman who has known a North Atlantic storm would cite the sea's own turbulence as its most destructive force. Waves, those "broad Atlantic combers", have wrought havoc on scores of vessels and claimed hundreds of lives. An errant wave broke a portlight in the column of the *Ocean Ranger*, and the consistent lateral force exerted by waves weakened a crossbrace of the *Alexander L. Kielland*. High waves can interfere with offshore operations by preventing diving manoeuvres and impeding the transfer of cargo to or from supply vessels. Extreme waves can force a drilling unit to disconnect for fear of damage to equipment, and swamp a lifeboat or life raft.

Those who study wave climate use historical data to describe waves in statistical terms, defining, for example, the frequency of occurrence of various wave heights and periods and variations among these values seasonally and from place to place.



3.6 The 100-year wave contour for the East Coast offshore, based on analyses by the Canadian Forces Meteorological and Oceanographic Centre (METOC).

Reliable estimates of the extreme wave height, of the period and of the crest height are of prime importance for offshore safety and among the key data required by designers and classification societies. Another area of widespread interest is the distribution of the kinetic energy of waves as a function of time and wave frequency. This factor becomes important in estimates of structural fatigue and as a basis for simulating sea states in modelling tanks.

The wave climate off eastern Canada has been studied in three ways: by using the technique of hindcasting, by employing visual observations and by measuring waves directly with instruments. Hindcasting is a procedure for deducing from archived weather data for a particular area the corresponding sea states of that area. Wind speed, direction, duration and fetch are derived from records of the atmospheric pressure field. These data are then used to calculate the height, the period and the direction of the waves which would have been produced. If 20 to 30 years of relevant meteorological data were available, it would be possible to generate a statistically sound description of the wave climate for deep water. For offshore eastern Canada there is only one hindcasting model which is considered acceptable but its coverage is limited to the vicinity of the Hibernia field. Other hindcasts are not dependable because they model the coastline incorrectly, ignore the presence of pack ice or cover too few years of data to be statistically reliable.

Many ships at sea participate in a worldwide program of reporting meteorological conditions; these data include visual observations of wave height, period and direction. In Canada, the wave data received through this program are used by the Canadian Forces Meteorological and Oceanographic Centre (METOC) to produce wave charts for the Northwest Atlantic. This information is prepared every 12 hours and is then broadcast as part of the marine forecast. As this program began in 1970 it provides a record long enough for useful statistical treatment and is the basis of a detailed analysis of wave climate for the eastern Canadian offshore.

For wave data measured instrumentally, buoys are deployed to measure the movement of the water directly as the wave passes. There are, however, limitations in the usefulness of data supplied by these instruments. Wave direction is not recorded, buoys may under-record large waves, the steepness of the wave front is distorted, and the area coverage is limited because it is impractical to deploy the buoys in sufficient numbers to be representative of a large area. Despite these limitations, data records of appropriate length obtained from these instruments are indispensable for many design functions and as a spot check on other methods of describing wave climate.

The two studies that can be directly compared are the Hibernia hindcast and the METOC analyses. They give respectively values of 30 metres and 28 metres for the 100-year wave, that is the height of the largest wave expected to occur in 100 years, and 15.1 metres and 15.6 metres for the 100-year significant wave height, that is the mean height of the highest one-third of the waves measured. This degree of agreement may be fortuitous. The uncertainty assigned to the hindcast is ± 10 percent. The reliability of the METOC estimates may be lower than this as they are based upon visual estimates made by individual observers. Thirty metres is the height of the 100-year design wave which has been used by the industry as a criterion in the selection and operation of rigs for Hibernia.

The wave climate of a large area such as offshore eastern Canada will vary significantly with location. The design wave estimated for the Hibernia area does not represent the entire region in which operations may be carried out. Wave regimes become more severe as the distance from shore increases. Figure 3.6 shows the contours of the 100-year maximum wave as derived in the METOC analysis. On the line from the Avalon Peninsula eastward past Hibernia, the gradient is about $+1.8$ metres per 100 nautical miles. The significance of this gradient is that the design wave for year-round operations eastward of Hibernia may need to be increased. On the Flemish Cap or the Tail of the Banks, the indicated increase is about 3 metres or

10 percent over the Hibernia figure of 30 metres. Because of the uncertainties underlying these numbers, it would be wise to have the wave hindcast and the METOC studies extended and refined to increase the geographical coverage and to improve the confidence limits on design wave values.

One gap in the scope of present measurements, which creates problems for hindcasting, is the lack of simultaneous wind, wave and current measurements. These elements interact in a complex manner which is not fully understood. A reliable series of simultaneous data would help establish the relationship between wind, waves and currents in particular areas and allow designers and classification societies to develop hindcasts of current extremes, a process which is not now possible. These data would also have important implications for sea-state forecasting.

Wave studies to date have not incorporated the effects of shoaling bottom or of currents on wave properties. In water shallow enough for bottom effects to play a major role, as around Sable Island, this situation creates serious data deficiencies. Much remains to be learned about the physics of complex wave trains as they move into shallow water, often under the added effect of strong currents, before a reliable description can be provided of this special case of wave climate and its extremes. Scientists in Germany, Holland and the United Kingdom have recently reported some success in modelling wave generation and propagation in shallow North Sea waters. This work is indicative of the growing attention being given to the subject as it affects not only design criteria, but also such operational considerations as diving, siting of jack-up rigs, and station-keeping. There is an evident need for ongoing, longer term research to resolve this scientifically difficult problem as it applies offshore eastern Canada.

There are, then, a number of specific areas affecting offshore design and operations where more information and research relating to wave climate are needed. These areas include improving the methodology of estimating extreme waves, strengthening the research effort on the prediction of the wave regime in shallow water, and conducting definitive investigations on the interactions between wind, sea state and currents. It is also important to ensure the long-term continuity of instrumented wave recording at selected sites in order to provide essential calibration points for predictive wave climate models, and wave spectra for use in the analysis of structural fatigue in rigs and other design applications. Finally, improvements in wave recording, including wave direction, would increase the reliability and utility of wave data.

The wind, both friend and foe of the mariner, has normally little direct effect on the safety of offshore operations, other than helicopter flights. Of greater significance are its secondary effects in generating waves, currents and sea spray and in moving icebergs. Study is needed to define the nature of these interactions and also to resolve a number of problems relating to the measurement of winds for offshore applications: the vertical profile of wind in the marine atmosphere, particularly at anemometer height, which in the case of rigs can be up to 80 metres above the sea; the effects of structures such as rigs on the wind field; and the optimum averaging time for wind measurements at sea. Estimations of extreme winds also need refining, and firm figures for 100-year design winds should be developed for different areas of Canada's Continental Shelf.

In addition to the winds sweeping over the ocean, the ice covering its surface and the waves and currents churning its depths, the seabed itself has a bearing on the safety of certain offshore operations. Jack-up drilling rigs, anchors and subsea equipment all make direct contact with the ocean floor. The most critical interaction is with jack-up rigs which depend completely on the seabed for their support and which are susceptible to a variety of foundation problems. The most serious of these as it affects the stability of the rig is punch-through, a situation which generally occurs when the rig is jacking up on location, and one leg penetrates a supposedly solid footing area to drop into a soft layer of soil below, plunging rapidly until solid resistance is encountered at some lower level.

Because of the threat to both equipment and human lives represented by punch-through, accurate knowledge of the bearing capacity of the seabed is a necessary prerequisite to siting jack-up rigs. Seabed information is available for most of the eastern Canadian offshore in the form of maps showing the distribution of various types of sediments and rock outcrop. Maps alone, however, are insufficient for selecting an actual drilling site, and for identifying potential punch-through conditions. The usual practice is to conduct a detailed site-specific survey which includes geophysical as well as soil testing and bottom sampling techniques. In some cases, sampling to some depth into sediments by borehole drilling is necessary to define foundation conditions.

At the present time the use of boreholes is discretionary in surveys for siting jack-ups. Existing statutory regulations applicable to the eastern Canadian offshore do not specifically require geotechnical investigations at drill sites although guidelines describe the geophysical and geotechnical information which may be appropriate and require that a report be submitted and signed by a professional geophysicist or geologist. There are those in the industry and the scientific community who feel that borehole sampling should be mandatory for the selection of jack-up rig sites and their arguments are convincing. A draft guideline requiring borehole sampling has recently been issued by the Canada Oil and Gas Lands Administration (COGLA) for comments from the operators.

In light of the many environmental hazards that confront those exploring for oil and gas off Canada's eastern shores, there can be little question about the importance of accurate forecasting. Precise foreknowledge of the timing, intensity, rate of increment, duration and path of storms, high winds, fog, or icing conditions all represent vital input into daily operations, contingency planning and emergency procedures. The scale of predictions required ranges from the very broad to the very narrow; long-term forecasts influence the planning for seasonal drilling programs, reliable 48-hour notice of approaching storms or ice is needed to prepare rigs, and in extreme cases to evacuate personnel, while precision forecasts on a time scale of a few hours are called for by helicopter pilots planning regular or emergency flights. An assessment of the quality of forecasts available to industry off the East Coast of Canada shows a need for improvements in their accuracy, their content, their analyses and their transmission; nevertheless, existing forecasts are recognized as being the best currently available.

One of the fundamental obstacles to effecting improvements in forecasts is the lack of sufficient real-time observational data. This is data which is observed and reported immediately as opposed to being stored for subsequent analysis or distribution. Although all operating rigs are part of the observational network, the present real-time coverage of weather in the offshore area of eastern Canada is far below that available for land-based forecasting.[2] The scarcity of observing stations in the open ocean is a common problem all over the world, and a number of solutions are being proposed. One of the most promising developments is the application of satellite-borne technologies to collect data by remote sensing over large areas of ocean.[3]

[2]A project was recently launched off eastern Canada to assess the usefulness of inexpensive, small, moored buoys measuring only atmospheric pressure and sea temperature as a means of adding to the observing network. Buoys were moored at three sites along the southern flank of the Grand Banks. They transmitted data via satellite to the Atmospheric Environment Service throughout the winter of 1984.

[3]Satellite-borne instruments include a scatterometer which is capable of measuring wind speed and direction over large areas of sea and an imaging or synthetic aperture radar which can penetrate fog and cloud cover. Canada has undertaken a project called RADARSAT which will launch a remote-sensing satellite by 1990. The purpose of this project is to collect observational data in the Northwest Atlantic which is not available at present. Final selection of sensors has not been made, nor have orbit or other details been finalized pending identification of user requirements.

Another fundamental problem facing meteorologists which has some repercussions in forecasting for offshore regions is the refinement of the present synoptic or large-scale marine forecast to take account of mesoscale or mid-scale phenomena. These phenomena include squalls and polar lows that are capable of producing hurricane force winds, yet they extend over a small enough area to go undetected by the network of observing stations. Squalls are known to be associated with narrow bands of precipitation embedded in the structure of a low pressure system. The bands may be as narrow as 20 kilometres and extend over as little as 100 kilometres, with life cycles as short as 2 or 3 hours, yet wind velocity changes of more than 50 knots can occur within the band. The physical nature of mesoscale phenomena is not fully understood and this factor is hampering the development of models capable of usefully forecasting mesoscale events. This problem is receiving attention worldwide, and a major study of the East Coast area, the most comprehensive study of storms ever undertaken in Canada, has recently been launched. A prominent feature of this study, the Canadian Atlantic Storms Project (CASP), is that it is a joint meteorological and oceanographic venture.[4] Projects of this nature hold considerable promise for improving forecast quality along the Atlantic seaboard and consequently for promoting the cause of safety offshore.

There are also other ways of improving the quality of forecasts. Verification, for example, determines how well a forecast measures up to the actual conditions experienced at the site. The results of verification procedures are important in establishing the level of credibility of a given forecast service. The verification procedures used by the private firms servicing offshore areas of eastern Canada and the Atmospheric Environment Service (AES) are, at present, not always consistent with one another, a situation which should be rectified. The interpretation of existing forecasts on board the rigs also needs improvement. Methods of forecast presentation could be upgraded through the use of television and computer technology which would provide two-way visual communication between sea and shore permitting the transfer of more detailed information in a more useful form, and rig personnel should be better trained in interpreting environmental information.

The hostile nature of the marine environment offshore eastern Canada leaves no room for complacency on the part of those who would operate industrial endeavours within its reaches. A solid foundation of environmental knowledge and its perceptive analysis form the only logical bases for sound decisions affecting all aspects of design, construction and operations. Those scientists who seek to decipher this complex environment and to offer guidance to offshore administrators, consider most aspects of this marine climate inadequately documented. This situation holds particularly true for analyses of 100-year or extreme events which require long periods of high quality data. But the extent and reliability of the data base itself are only part of the problem. There are also agreed-upon weaknesses in the present system of managing, analysing, and disseminating marine environmental data to prospective offshore users.

The entire information process is an intricate one – from the initiation of a program to the application of results, through publication to final archiving of properly processed original data in an accessible data bank. It involves questions of proprietary rights, restricted access, relevance to user requirements and the need for some

[4]The meteorological objectives of CASP are to study the movement and evolution of large scale storms that affect the area; to understand the processes responsible for and the characteristics of mesoscale features embedded within these storms; to examine the relationships between storms and the ocean and between storms and ice fields; and to develop forecasting techniques using satellite and weather radar data for severe winds and precipitation associated with these storms. The oceanographic component of this project will study the relationship between currents, waves and local winds, as well as the behavior of storm waves in shoaling waters. The field program is scheduled for the early months of 1986 to coincide with a corresponding United States experiment called GALE. Together these studies will provide a unique data base for numerical modelling studies of storm evolution along the Atlantic seaboard.

sort of co-ordination between government and industry in the planning, collecting and managing of this resource. The Canadian Petroleum Association has recently proposed that industry and government begin to address future environmental data needs offshore by establishing a task force to develop a co-ordinated data management system. A joint approach of this kind would meet the requirements of both users and regulators and should not be postponed.

As more information and better analytical techniques become available, environmental maps similar to those issued for the North Sea by the United Kingdom Department of Energy could be developed, kept up to date, and distributed regularly. These steps should effect significant improvements in the level of certainty to be ascribed to design and operational criteria and, by extension, in the maintenance of offshore safety.