UMR Journal -- V. H. McNutt Colloquium Series

Volume 2 Article 14

June 1971

Arctic Marine Terminals -- Some Environmental and Engineering Considerations

Robert L. McCollom Jr.

William W. Moore

Arctic Marine Terminals-Some Environmental and Engineering Considerations

Robert L. McCollom, Jr.
Dames and Moore
Anchorage, Alaska

and

William W. Moore
Dames and Moore
San Francisco, California

ABSTRACT

Studies are presently underway to determine the technical and economic feasibility of various Arctic marine transportation systems, including ice-breaker super-tankers and submarine tankers. An important consideration in these studies is the design and construction of marine terminal facilities which will be suited to the unique problems of the Arctic. Factors which will significantly affect the design of proposed marine terminals include:

1) bathymetric configuration of the continental shelf;
2) influence of moving pack ice on artificial structures, both at the air-water interface and along the bottom;
3) lateral and vertical variations in soil conditions, including residual permafrost, which might adversely affect stability of offshore pipelines or structures; and
4) instability of existing shoreline.

Several basic designs for marine terminals are considered with respect to environmental and engineering problems including:

1) nearshore harbor sheltered by a breakwater;
2) offshore artificial islands;
3) underwater terminals; and
4) cone-shaped offshore platforms, either pile supported or gravity-type structures.

INTRODUCTION

Recent discoveries of petroleum reserves at Prudhoe Bay in Alaska and Atkinson Point, N.W.T., Canada have initiated a number of studies regarding feasible methods of transporting the Arctic oil and gas to the major markets in southern Canada and the United States. Various pipeline routes have been considered through Alaska and Canada, but for technical, economic and political reasons construction has thus far been delayed.

For several years, industry has been considering the feasibility of utilizing ice-breaker super-tankers which would travel from the Arctic through the Northwest Passage to refineries and markets in the east. More recently a concept involving the use of submarine tankers which would be capable of crossing the North Pole to European markets as well as negotiating the Northwest Passage has been proposed (Figure 1).

As part of the feasibility study for transporting petroleum by tanker, consideration is being given to the location, design, construction and maintenance of petroleum storage facilities and marine terminals in the Arctic. Numerous environmental and engineering factors will have to be considered before the technical and economic feasibility of the project can be determined.

Because of the need to provide petroleum transportation systems which will virtually eliminate potential oil spills, the design for any proposed marine terminal will undergo extensive scrutiny by the various governmental agencies before approval. Preliminary data regarding ice movement and soil conditions are presently being collected for design purposes; however, additional studies will be required before all the engineering problems can be resolved.

ARCTIC CONTINENTAL SHELF

The broad, shallow shelf along the Alaskan Arctic coastline presents considerable design problems for the construction of a marine terminal which would accommodate deep draft tankers. As shown on the bathymetric map of the Beaufort Sea (Figure 2), water depths of 80 to 100 feet required for deep draft supertankers are no closer than 25 miles from shore in most places along the Alaskan Arctic coast. Long, narrow, barrier islands present along some areas of the coastline help bridge this gap somewhat but considerable distance still remains between tanker and shoreline. The only viable alternatives to the bathymetric problem appear to be either: (1) bring the tankers

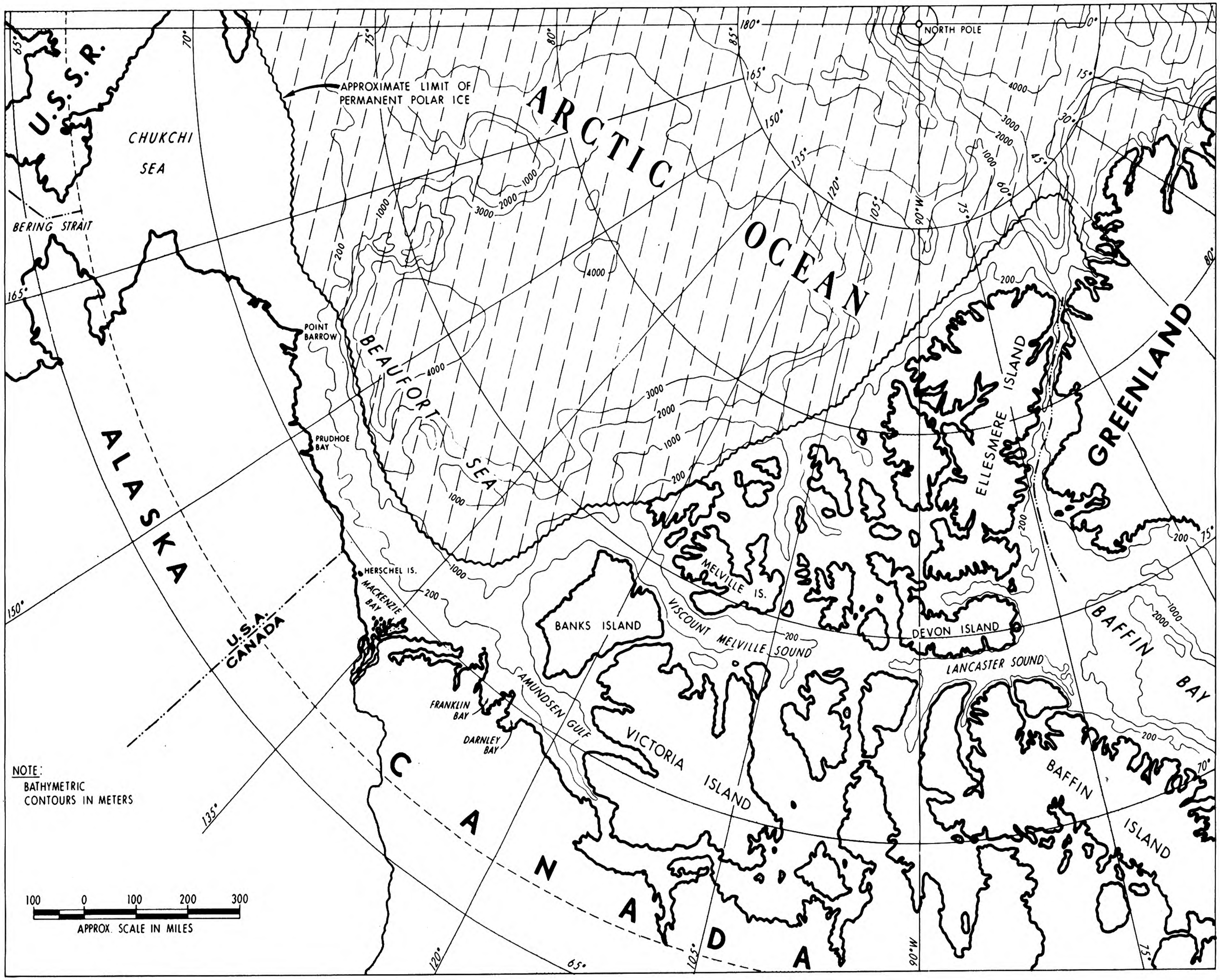

Figure 1. Canadian and Alaskan Arctic

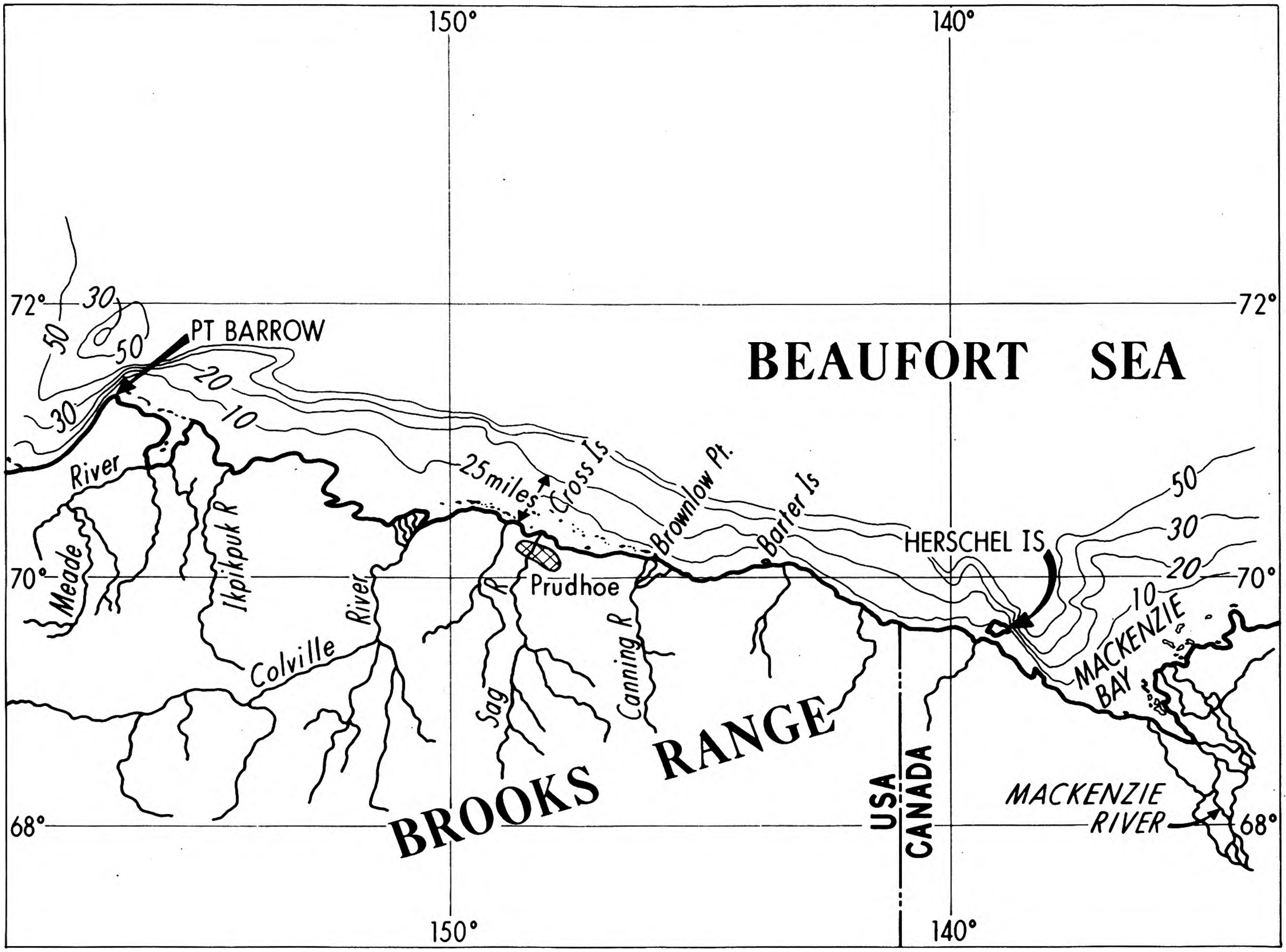

Figure 2. Bathymetric Map of the Beaufort Sea (Contours in Fathoms)

closer to shore by dredging a channel or (2) construct a deep water marine terminal which would be connected to onshore storage facilities by submarine pipeline.

The engineering and economic considerations for either alternative are staggering. For example, to dredge a protected harbor and a channel northward from Prudhoe Bay out to 80 feet of water would require dredging between 500 and 700 million cubic yards of material. Areas closer to deep water such as Cross Island and Brownlow Point would still require 50-200 million cubic yards of dredging. In addition, the channel would have to be maintained periodically to prevent sedimentation from blocking passage of the deep draft tankers. Much of the dredging would have to be accomplished out in the moving ice pack. A portion of the area dredged is likely to contain remnants of permafrost which would be difficult to dig with conventional cutter heads. A system of breakwaters or submerged barriers would have to be provided to protect the channel area from blockage by ice islands or thick pressure ridges. The other alternative, constructing a deep water marine terminal, requires that an artificial platform be designed and constructed to withstand the tremendous forces generated by the polar ice pack.

ICE FORMATION AND MOVEMENT

The most formidable problem in the design of a deep water marine terminal is the movement of large masses of sea ice which will impinge on support structures. Sea ice forms in sheets generally reaching a maximum of 6 to 10 feet in thickness depending on the degree days of frost during its formation and subsequent yearly build-up.

The ice may be divided into three zones: shore-fast ice, pack ice and a transition zone between the two. Shore-fast ice normally extends from the shoreline out to the island chain and, under certain wind and ice conditions, some distance beyond the islands. The term "shore-fast" is somewhat a misnomer in that the ice sheet is not always a continuous mass connected to the shoreline. Minor lateral movement has been noted on occasion in areas which otherwise appear to be shore-fast.

Beyond the relatively stable shore-fast ice is pack ice, a mobile mass of irregularly broken ice sheets, pressure ridges and occasional ice islands which move primarily in an east-west direction in response to wind stresses (Figure 3). Pack ice has been known to travel several miles during a day although there are times when little movement takes place at any given location.

The transitional zone varies in width and character. At times it is marked by leads which separate stable ice from the mobile ice floes. At other times the zone is characterized by pressure ridges and irregular blocks of ice which are partially mobile.

Assuming that a deep water marine terminal would be constructed in water depths of 80 to 100 feet to accommodate deep draft tankers, the terminal supporting structure would be subjected to tremendous horizontal forces exerted by the pack ice. According to Gerwick and Lloyd (1970), "a relatively long wall with a b/h ratio (b is breadth of structure, h is ice sheet thickness) of 15 or more would be subjected to loads of 45 kips per square foot." For a slender vertical wall of 25 feet in width with a b/h ratio of 4, an ice sheet 10 feet thick would impose a load of 95 kips per square foot. Assuming the vertical structure to be a cylinder rather than a wall, the loads would be modified by the shape factor and would be, in each case, about 10% less. If a pressure ridge rather than sheet ice were to impinge on the structure the loads imposed would be approximately 2.2 times as great.

Another problem in addition to the loading factor is the effect of ice pile-up on the structure. "In general pile-up will occur if the ratio b/h is greater than 15. For ratios of under 15 the ice will tend to split and pass on either side of the obstruction. Thus, for structures with a width of 80 feet or more, pile-up can occur" Gerwick and Lloyd (1970).

In addition to the effects of ice at the air-water interface, potential hazards exist due to gouging of the ocean bottom by grounded ice islands and pressure ridges. It is not likely that this would effect the structure itself significantly; however, any underwater pipeline leading to the terminal structure would be subjected to possible rupture by the ice unless it were adequately protected.

FOUNDATION CONDITIONS

The arctic presents unique problems with respect to foundation engineering due primarily to the presence of permafrost. In its undisturbed state permafrost is relatively solid and stable. If, however, the thermal regime is disturbed, precautions must be taken to compensate for thaw consolidation which takes place as the ice in the soil begins to change phase.

On the North Slope of Alaska the permafrost is relatively thin near the foothills of the Brooks Range and thickens rapidly northward toward the coastline reaching a maximum thickness of slightly over 2000 feet. Due to the warming effect of the Arctic Ocean, the permafrost wedge pinches out rapidly north of the coastline. The lateral extent and depth to which permafrost occurs offshore is unknown due to the lack of adequate subsurface information. Permafrost has been reported to a depth of several hundred feet along the barrier islands. Isolated patches of permafrost beyond the island chain and in certain offshore areas along the Canadian coastline have been reported but it has been assumed that these represent areas of relict permafrost which are gradually being thawed by by contact with the sea water and are not very extensive. The extent to which permafrost is present between the shoreline and the island chain remains to be resolved.

There has been some speculation as to why permafrost still exists in some offshore areas. Theoretically, the heat exchange between sea water at temperatures above 0° C and the frozen ground would gradually thaw any permafrost which might be present. This would certainly be the case if the shoreline were to remain stable for sufficient time to allow a complete thawing process. However, the shoreline has not proven to be very stable due primarily to a process of erosion which has been active at least during late Pleistocene and Holocene time. MacKay (1963) has estimated that since the period of the last glaciation, coastal recession along portions of the Yukon coastline may have been as much as 2 or 3 kilometers. He also suggests that in coastal areas with low bluffs of fine grained sediments which have a high ice content, shoreline recession may occur at a rate exceeding one meter per year. As the bluffs recede, the sea water transgresses across the permafrost depositing a thin layer of silt and clay up to 5 feet in thickness on top of the remaining frozen ground. The sediment provides an insulating layer which inhibits the heat interaction between the sea water and the frozen

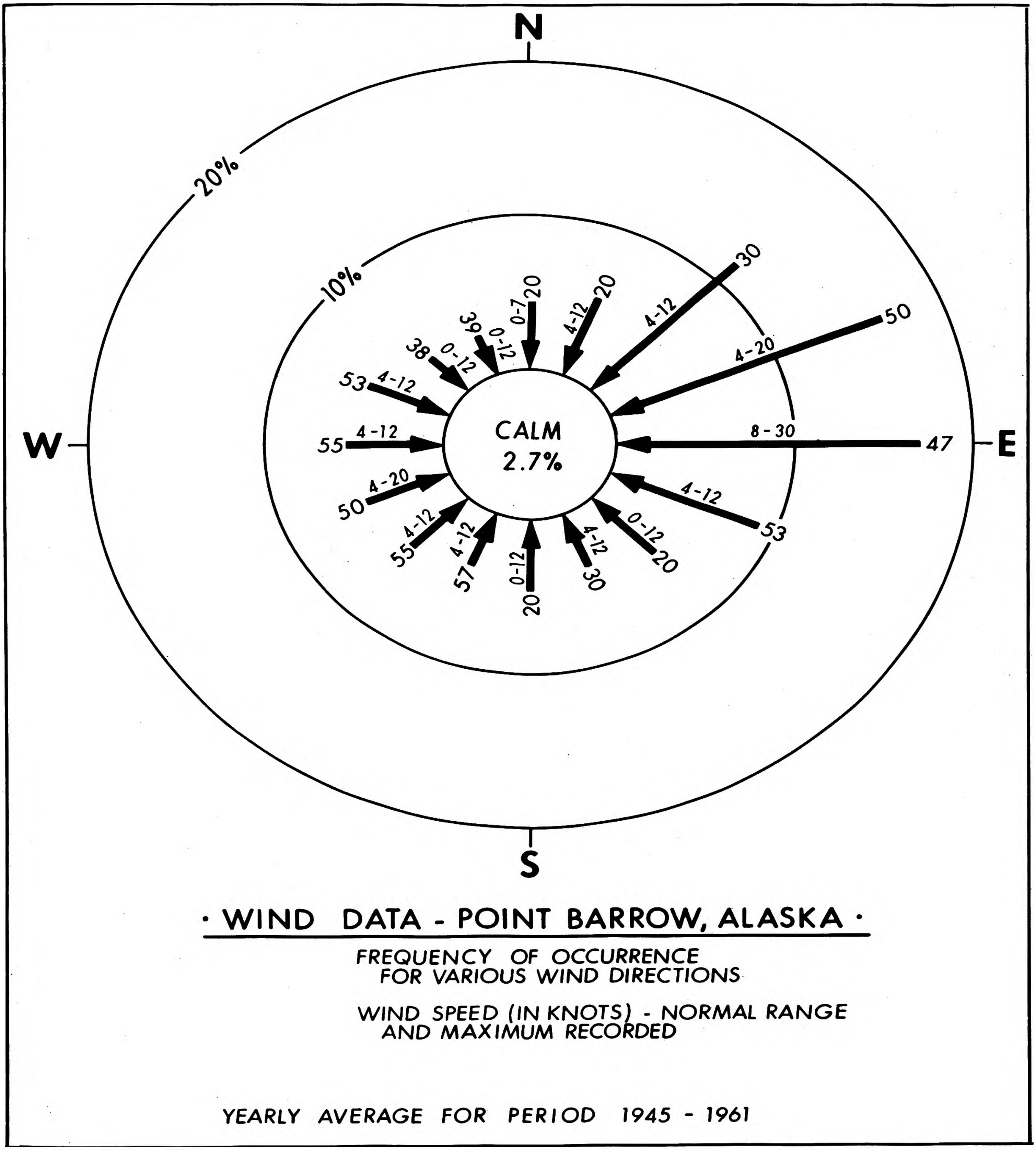

Figure 3. Wind data, Point Barrow, Alaska.

ground resulting in patches of "relict" permafrsot offshore.

It has been suggested that in some instances frozen ground has actually been formed after being submerged beneath the ocean. In these cases, it is presumed that brackish or fresh water migrating in the sedimentary material beneath the ocean floor is gradually exposed to the effects of overlying sea water at temperatures slightly below 0° C. The fresh water then freezes and becomes permafrost, similar in most respects to permafrost conditions onshore. It has been postulated that this mechanism was responsible for the formation of the submerged "pingo" which the Manhattan encountered on her voyage through the Northwest Passage in 1969.

It is not likely that substantial permafrost would be encountered at the site of a deep water terminal due to its water depth and distance offshore. However, a portion of the nearshore area is likely to contain some permafrost which will have a bearing on the design and construction of the underwater pipeline leading to the terminal.

The soil conditions along the Alaskan Arctic coastline are quite variable in their make-up both laterally and vertically. This is due primarily to the braided streams channels which flow northward to the sea. The channels, which are usually filled with sands and gravels, cut into the surrounding finer grained silts, sands, and clays, resulting in rapid lateral changes in soil conditions. It is likely that this condition extends beneath the ocean bottom some distance offshore as a result of variations in sea level which might have occurred during and subsequent to Pleistocene time. In order to insure that the foundation of a marine terminal facility will be adequately designed to withstand the horizontal forces exerted by ice floes, soils data will have to be collected at the terminal site. The technical feasibility of drilling soil borings from a mobile ice sheet in 100 feet of water does not, however, at the present time look very promising.

PROPOSED OFFSHORE TERMINALS

A number of possible designs for marine terminal facilities have been suggested which might be suitable for deep water tankers, four of which offer promise.

1. Nearshore harbor sheltered by breakwaters

Although the Alaskan Arctic shelf is relatively borad and shallow, there are a few areas where water depths of 80 feet or more come within ten miles of land. One of these is at Cross Island, the northern-most of the barrier islands near Prudhoe Bay. The island, although somewhat limited in size, has shallow water surrounding it which might be filled to provide adequate area for storage tanks and other facilities. Approximately 10 miles northeast of the island there is sufficient water depth to accommodate deep draft tankers. A short channel could be dredged and a breakwater provided to protect tankers from pressure ridges or other large ice masses which might move into the area. A 12 mile long pipeline would be required to transport crude oil across the lagoon from Prudhoe to the storage area on the island.

Another location, at Brownlow Point, approximately sixty miles east of Prudhoe Bay has close access to deep water. Water depths in excess of 80 feet are found at distances less than 6 miles offshore and there is adequate onshore areas for location of storage tanks and other terminal facilities. However, the area is considerably removed from present oil production and would require a long pipeline to terminal facilities. If later exploration proves up additional production east of Prudhoe, this area might be more feasible from an economic standpoint.

A third possible location for construction of a harbor for petroleum terminal facilities is at Herschel Island along the Yukon coastline approximately 45 miles east of the U.S. - Canada border. Herschel Island is favorably located with respect to deep water, near the edge of the Mackenzie submarine canyon, and has a natural sheltered deep water basin immediately to the south (Ranftomel McCollom, 1970). Although dredging of approximately 20-50 million cubic yards of silt and clay would be required to connect the basin with the submarine canyon, the harbor would provide excellent shelter from the pack ice.

There are several other areas eastward along the Canadian Arctic coastline including Franklin Bay and Darnley Bay which may be economically feasible as potential marine terminals for Canadian crude production; however, these are not as suitable for Alaskan petroleum reserves.

2. Artificial Islands

Artificial islands have been considered on the North Slope primarily for use as drilling platforms but also as a possible alternative for an offshore marine terminal. The water depth requirements for deep draft tankers would require considerable material for construction of the island but borrow material dredged from a channel leading to the island could provide a portion of the required fill. Interlocking precast armor units might provide additional strength against the pack ice. As suggested by Gerwick and Lloyd (1970), "precast prestressed concrete embankment units could be placed as slope protection. They would presumably be unloaded from a barge, floated into position, then sunk and filled with gravel to act like a rock-filled crib. A trapezoidal cross-section appears most suitable, as it permits ice to initially ride up and fail in tension."

The artificial island might be constructed in several ways: (1) a solid mass with loading facilities on the lee side of the island depending on ice movement or (2) crescent-shaped islands-one facing east, the other west-providing a protected harbor in-between (Figure 4).

3. Underwater terminals

If submarine tankers are to be used for petroleum transportation, the most obvious terminal would be a facility located on the ocean bottom in deep water. This removes many of the engineering design problems associated with pack ice. The terminal might be constructed to permit a submarine tanker to locate over the loading facility and by means of remote control transfer crude from underwater storage to the submarine tanker.

The major problems with this system are the same as those which would occur during construction of any facility out beyond the shore-fast ice, namely interference by the pack ice.

4. Offshore platform

Perhaps the most technically and economically feasible concept for an offshore marine terminal offered thus far is a conical shaped platform designed by Santa Fe-Pomerory (Gerwick and Lloyd 1970) or a similar structure designed by Thermo-Dynamics, Inc. The platform consists of two cones, one inverted on the other. As the pack ice impinges on the cone shaped structure, the slope "converts a purely horizontal shear to a partially vertical thrust, with the softer underside of the ice meeting the steel shell first so that the ice helps break itself up as it flows past" (anonymous, 1970).

The base of the cone should be of adequate size to provide a bearing area sufficient for support on the softest soil anticipated. The platform could be stabilized either by means of gravel fill, drilled-in and grouted anchor piling, or ice-filled compartments. The portion of the cone above water would be surmounted by a return ice deflector to prevent over-topping by ice pile-up. Inside the cone would be living quarters, machine-

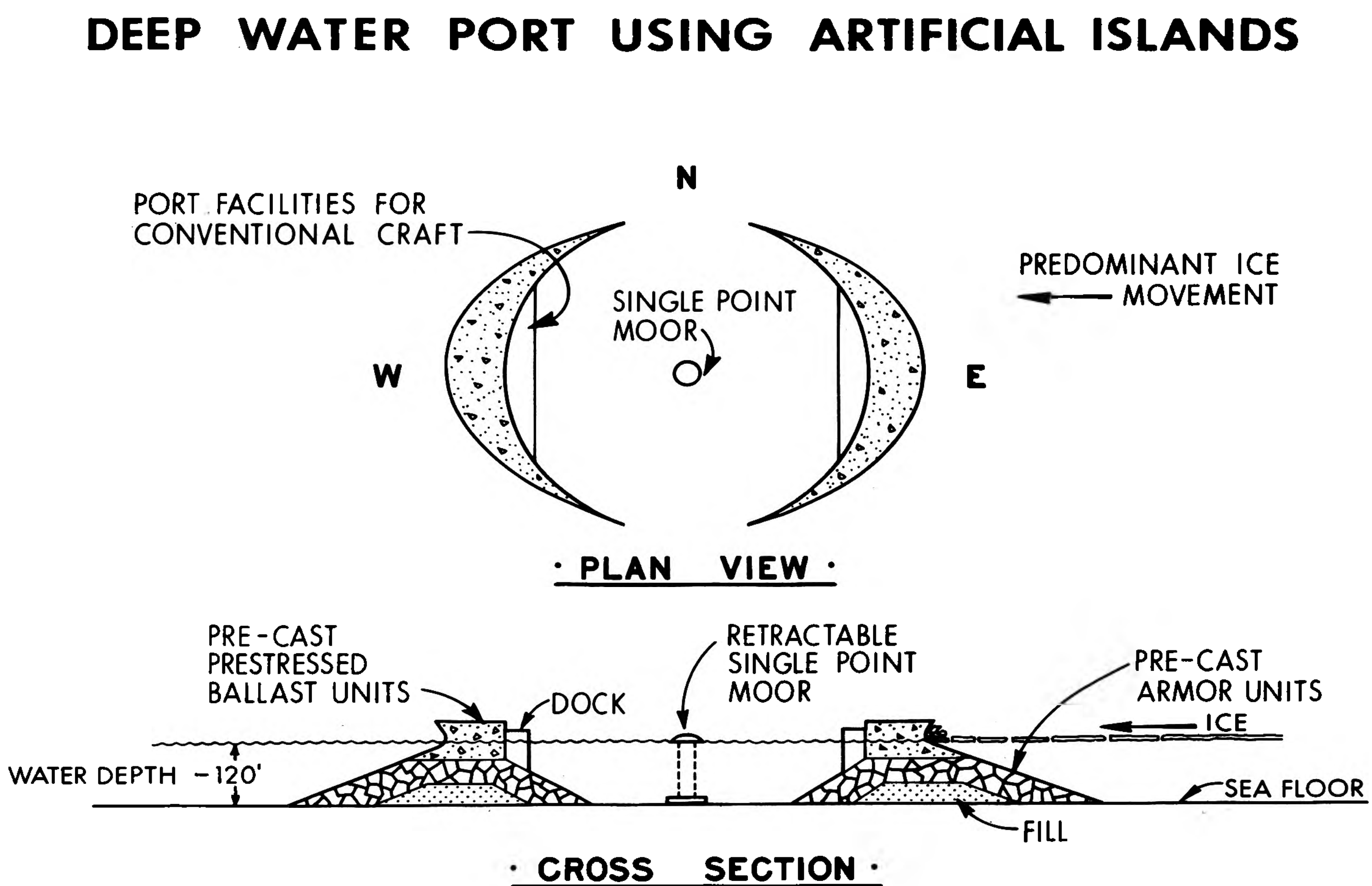

Figure 4. Deep water port using artificial islands.

ry spaces, water and oil storage tanks, provisions for risers, submarine pipeline connections and diver access tubes (Figure 5).

CONCLUSION

The Arctic Ocean presents perhaps the most formidable challenge that the oil industry has ever undertaken. The historic voyage of the Manhattan marks the opening of a new era of opportunity for development of the vast resources in the Arctic. Pipelines undoubtedly will be built to transport both crude oil and natural gas to the lucrative markets of Canada and the United States. However, the use of marine tankers is inevitable in the overall development of the Arctic's resources. It is possible that in addition to transporting oil through the Northwest Passage, surface or submarine tankers may eventually traverse the polar route to potential markets in Europe.

The engineering and environmental problems involved in the construction and design of marine tankers and terminals are formidable, but the ingenuity and resourcefulness provided by industry, government and the academic community will eventually triumph as they have in conquering every new frontier in the past.

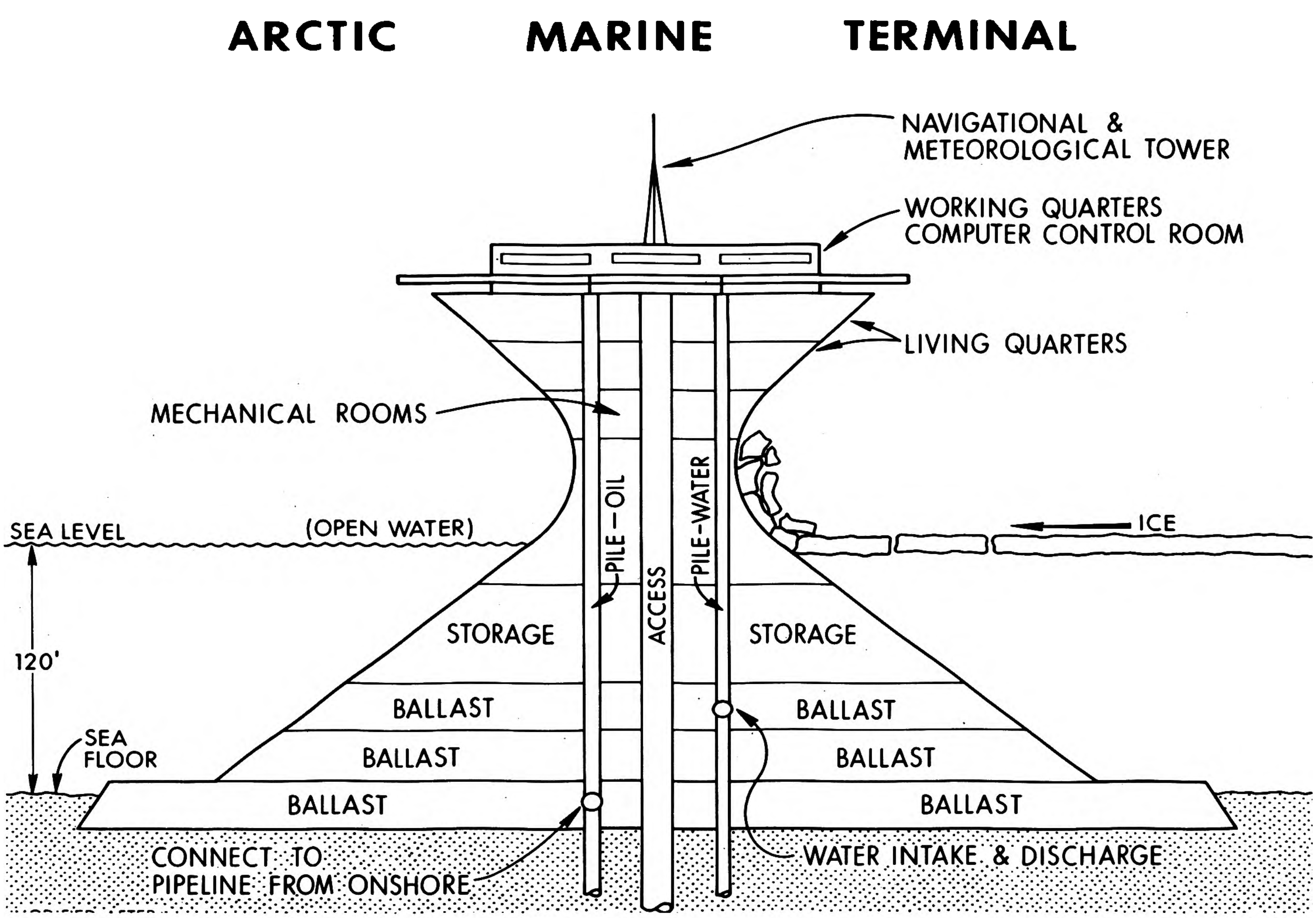

Figure 5. Arctic marine terminal.

Robert L. McCollom, Jr.

Mr. McCollom attended Dartmouth College where he received a B.A. degree (major in geology) in 1957. He received a M.S. degree in geology in June, 1959 from Stanford University.

From 1958 until 1968, Mr. McCollom was employed as an exploration geologist for Standard Oil Company of California working in Texas, the Pacific Northwest and California. His experience includes extensive offshore exploration utilizing a variety of geologic and geophysic techniques. In connection with his work Mr. McCollom, as representative for five major oil companies, was responsible for the planning and supervision of an underwater geologic mapping project in the Santa Barbara Channel utilizing a two man submarine.

Mr. McCollom joined the firm of Dames & Moore in 1968, and was assigned to their New York offices as Senior Marine Geologist. There he was responsible for the firm's oceanographic projects including the planning and supervision of marine surveys in Canada to determine the feasibility of utilizing tides for generating power. He also has experience in conducting environmental studies for nuclear power plants, refineries, offshore platforms, pipelines and ocean disposal systems.

Mr. McCollom has conducted several geophysical, oceanographic and engineering geologic studies in Cook Inlet and southeastern Alaska. His experience in Arctic problems pertains to environmental studies for proposed marine terminals, pipeline routes and foundations in permafrost areas. He is presently manager of Dames & Moore's Anchorage office.

REFERENCES

Anonymous,, 1970, Portable frozen fill for arctic offshore drilling: Alaska Construction and Oil., Sept. 1970, p. 86-87.

Blenkarn, K.A., 1970 "Measurement and analysis of ice forces on Cook Inlet structures *OTC 1261,* Preprint Vol II: presented at Second Annual Offshore Technology Conference, (April, 1970).

Breslay, L.R.; James, J.E.; Trammel, M.D. and Belike, C.E., 1970. The underwater shape of a grounded ice island off Prudhoe Bay, Alaska: *OTC 1305,* Preprint Vol II: presented at Second Annual Offshore Technology Conference.

Breslau, L.R.; Johnson, J.D.; McIntosh, J.A. and Farmer, L.D., 1970, Development of arctic sea Transportation-Environmental Research Marine Technology Society Journal, Vol. 4, No. 5, P. 19-43.

Fryer, Mark, 1970, Planning marine structures for Alaska's arctic regions: The Northern Engineer Vol 2, No. 1, p. 17.

Gerwick, B.C. Jr and Lloyd, R. R., 1970, Design and construction procedures for proposed arctic offshore structures: Oct. 1260 Preprint Vol. II, presented at Second Annual Offshore Technology Conference.

Lewellen, Robert I., 1970, Permafrost erosion along the Beaufort Sea Coast: Univ. of Denver Geography and Geology Dept. March, 1970.

MacKay, J. Ross, 1963, Notes on the shoreline recession along the coast of the Yukon Territory Arctic Vol. 16, No. 3, p. 195-197.

Ranft, F.E. and McCollom, R.L., 1970, Environmental studies for a proposed arctic marine terminal: *SPE Paper 2943,* presented at Society of Petroleum Engineers Fall Meeting (Oct. 1970).

Soros, Paul, 1970, Offshore mineral terminals - artificial islands and open - sea shiploading of dry bulk materials: *OTC 1235,* Preprint Vol. II, presented at Second Annual Offshore Technology Conference, (April, 1970).