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SHORELINE PLANNING AND RESPONSE IN ICE-DOMINATED ENVIRONMENTS

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ABSTRACT 299636:

Many existing or developing offshore production areas and transportation routes are in the Arctic or in marine areas that have seasonal ice. In many respects, the shoreline types of cold-climate or ice-dominated regions are similar to those of ice-free environments. Our knowledge and understanding of shore zone materials and coastal landforms from warmer regions is applicable to these environments in most respects, with the addition of ice and snow and the presence of arctic tundra, glaciers and ice sheets. Oil behaves differently in cold climates depending on the source of the oil, the oil character, and the presence and character of ice and/or snow. A shoreline would be protected from direct contact by oil when ice is present in the shore zone. Ice is impermeable so that oil deposited on the surface remains there unless there are cracks in the ice, the ice conditions are floes grounded on the shore, or during the formation of shore fast ice. Shoreline cleanup methods are not significantly different and no more difficult that in warmer, ice-free regions, except on ice and low-lying arctic tundra. The key challenges for a shoreline response in ice-dominated environments typically are associated with remoteness, safety and logistics. As a result, the emphasis for shoreline cleanup strategies is on *in situ* treatment techniques that require minimal equipment and manpower resources and generate little or no waste.

INTRODUCTION:

The primary feature of cold climate shorelines is the presence of ice and snow for some part of the year. Shore-zone ice and snow can occur in a number of forms in latitudes as far south as 40ºN (e.g. Cape Cod, Bohai Sea). Excluding inland seas, such as the Great Lakes, the Caspian Sea, and the Sea of Azov, as much as an estimated 45% of the world's approximately 850,000 km of ocean coastlines can have seasonal snow or ice.

Snow plays a relatively minor role in shore-zone processes whereas ice is present in the substrate in a number of forms and is an active process that redistributes sediments. Understanding coastal processes and the character of shoreline features that form in ice-dominated environments is essential to the development of effective response strategies and plans for those regions.

This discussion describes the features of ice in the shore zone; the behavior of oil and ice in the shore zone; detection and delineation tools; shoreline sensitivity and protection strategies; and shoreline clean up in ice-dominated environments.

SHORELINES IN ICE-DOMINATED ENVIRONMENTS

For the most part, the shoreline types of cold-climate regions are similar to those of ice-free environments. Our knowledge and understanding of shore zone materials and coastal landforms from warmer coastal environments is applicable to cold climates in most respects, with the addition of ice and snow and the presence of arctic tundra, glaciers and ice sheets.

The term "ice-dominated" refers to specific conditions related to both the presence of ice as a substrate material and as a physical process.

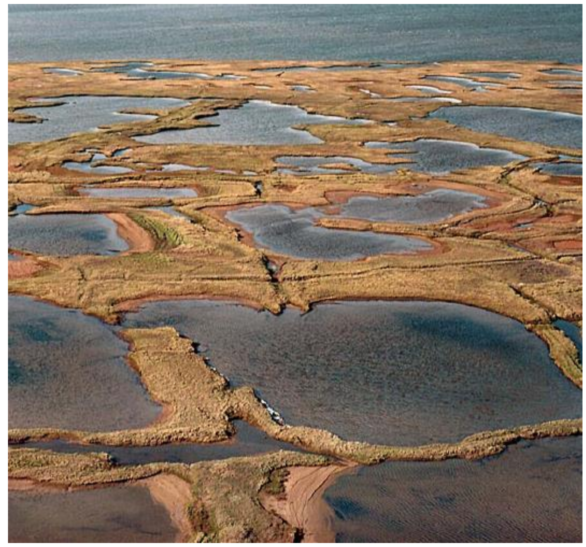
Ice Types in Ice-Dominated Environments

Ice is present in the shore zone as part of the substrate where:

- glaciers and ice sheets reach the coast,
- frozen ground ("ground ice") or permafrost is exposed in the face of a cliff (Figure 1D),
- frozen ground or permafrost underlies inundated coastal arctic tundra (Figure 1C),
- water in beach sediments freezes seasonally (Owens and Harper 1977),
- seasonal ice layers form as wave splash, spray, or swash freeze (Figure 1A), and
- fresh water flowing down slope from the backshore freezes on a shore.

Tundra shorelines and exposed permafrost in the coastal zone create a set off shore types that are unique to North America and Russia. Arctic tundra has a continuous plant cover composed of dwarf shrubs, grasses, mosses and lichens that is underlain by permafrost or seasonal ground ice. Low lying coastal tundra may be flooded or inundated by marine waters during spring high tides or wind induced surges (meteorological tides). The landward limits of past surge events usually are marked by log or debris lines. The surface topography may be characterized by ice-wedge polygons that form as water freezes in contraction frost cracks. This patterned ground is often water-logged in summer months as melt water is contained by the high polygon rims or where wave action breaches polygons or floods low-lying tundra. These low-lying inundated tundra areas often have a complex and convoluted shoreline (Figure 1C) and predominantly are a combination of vegetated flats, peat mats, brackish lagoons, and small streams (Hill and Solomon 1999). In areas of higher relief in the shore zone, the subsurface permafrost may be exposed where the easily erodible tundra vegetation is removed by wave action.

A. Grounded ice floes and frozen intertidal swash ice



C. Inundated low-lying high-rim arctic tundra polygons

B. Boulder barricade formed by ice rafting

D. Permafrost exposed in eroding tundra cliff

Figure 1 Examples of shore types unique to ice-dominated environments

Many cold climate coastal environments were glaciated during the last Ice Ages. One legacy of this period is the presence of large volumes of coarse sediment that were eroded and carried to the coastal zone by glaciers and glacial rivers so that the beaches of many glaciated regions are characterized by the presence of pebble, cobble, and boulder sediments (Davies 1972, Forbes and Syvitski 1994).

Shore Processes in Ice-Dominated Environments

Shore-zone processes are similar in most respects to warmer coastal environments. Our knowledge and understanding of shore-zone processes in warmer climates is applicable to cold-climate environments with the modifications necessary to account for the role and effects of ice. Typically, seasonal shore ice begins to form before nearshore ice and persists after the nearshore ice has broken or melted. The length the shore-ice season is therefore typically longer than the nearshore or offshore ice season. In high latitudes, the ice-free period may be only a few days or weeks so that wave and tidal processes that dominate warmer environments are limited and very little energy is available to rework shore-zone sediments or stranded oil. Arctic or cold climate shorelines are not necessarily low wave-energy environments, but the length of the open-water season may be shortened due to the presence of ice. Ice is, for the most part, a seasonal element that modifies the shore-zone character and acts as a process when:

- ice floes of various sizes that originate from the breakup of sea ice or from calving tidewater glaciers strand at the shore causing scour and thrusting (Figure 1A) (Forbes and Taylor 1994), and
- ice that forms at a shoreline is floated by a rising water level and moves sediment, vegetation or animals that are frozen to the underside of the ice ("rafting") (Figure 1B) (Lauriol and Gray 1980, Rosen 1979).

Shore Types in Ice-Dominated Environments

Shore types that result from the combination of ice as a substrate material and/or as a process in ice-dominated regions are:

- ice cliffs of "tidewater" glaciers and ice sheets,
- ice-rich arctic tundra cliffs with exposed permafrost (Figure 1D),
- inundated low-lying arctic tundra (associated with permafrost) (Figure 1C),
- boulder barricades, formed by ice rafting on intertidal platforms (Figure 1B),
- sediment ridges created by ice push or ice pressure ice is grounded ice on a beach, and
- ridges and scarred shores on coasts with fine-grained sediments (sands, silts and clays) in low wave-energy environments (Forbes and Taylor 1994).

Otherwise, the form and character of shoreline features when seasonal ice is not a factor are similar to those created by wave, tidal and wind processes in warmer environments.

OIL BEHAVIOR IN THE SHORE ZONE WHERE ICE IS PRESENT:

The behavior of oil in cold climates depends on the source of the oil, the oil character, and the presence and character of ice and/or snow. Spills onto shore ice or snow result from oil either being washed ashore when the adjacent waters are ice free, under-ice oil reaching shore and emerging in tidal cracks, from airborne oil resulting from a blowout, or from land-based spills that flow down slope to the shore.

Studies of oil on Arctic shorelines go back to a 1976 biodegradation experiment in Svalbard that demonstrated accelerated weathering by the addition of a commercial fertilizer (Sendstad 1980, Sendstad *et al*. 1984). This section summarizes the behavior of oil in the shore zone over a range of ice conditions.

Oil and Ice in the Shore Zone

A shoreline is protected from direct contact by oil when ice is present in the shore zone. Ice is impermeable so that oil deposited on the surface remains there unless there are cracks in the ice, the ice conditions are floes grounded on the shore, or during the formation of shore fast ice. The ways in which the presence of ice modifies oil behavior include:

- Surface oil that flows into cracks or leads in the transition zone where floating and shore-fast ice meet to the point where the holding capacity of the lead is exceeded so that oil then may be carried or trapped under the floating ice.
- Under-ice oil that reaches the shore and emerges to float on the water in the tidal crack or lead until the holding capacity is exceeded.
- The case of grounded floes which create a mixed environment in which the "normal" shore material may be oiled at the same time as oil coats individual ice floes that may refloated and moved with the tides or by wave action.
- Oil that can become incorporated within existing shore-fast ice or covered by newly formed ice by the freezing of wave splash, spray, or swash.
- The penetration of oil deposited on a beach that is ice free may be limited by the presence of subsurface ice (frozen groundwater in the sediments: Owens and Harper 1977).

In addition, the behavior of oil deposited on shore-zone ice is affected by air temperature. If the temperature is above freezing and the surface of the ice is melting, the presence of surface water may prevent oil from adhering to the ice, whereas if the temperature is below freezing the oil could readily adhere to the dry ice surface.

Oil and Snow in the Shore Zone

The behaviour of oil in snow is known largely from field and laboratory experiments (Bech and Sveum 1991, Carstens and Sendstad 1979, Mackay *et al.* 1975, Owens *et al*. 2005). The sorptive capacity of snow varies with oil type and snow character. Fresh snow typically has a low density and a high porosity and is a relatively effective sorbent for spilled oil so that light and medium oil may easily penetrate. This reduces surface spreading but this is offset by the increase of oil in the subsurface snow.

Under quiescent environmental conditions, snow can accumulate with a simple vertical variation in density and porosity and as snow thickness increases the weight of the overlying snow layer increases creating a more tightly packed structure as air spaces are eliminated and porosity decreases. In most situations, however, this steady accumulation is interrupted by the effects of freeze-thaw cycles and wind. Diurnal temperature oscillations around the freezing point are a common feature during the freeze-up period. These alternate ablation and freezing processes can generate ice layers as snow melts during daylight warm temperatures and freezes at night when temperatures drop below zero. If this freeze-thaw cycle is accompanied by precipitation, a range of features can form that may include alternate layers of snow and ice. Oil infiltration is limited by the presence of impermeable layers, such as frozen ground or ice layers within the snow column created by freeze-thaw processes.

The definitive work on the modeling of oil spills in snow by Belore and Buist (1988) generated process equations to predict the fate and behaviour of oil spills in or under snow. Evaporation is the single most important weathering process for oil trapped in snow. One study measured evaporation rates exceeding 50% by volume after 6 days exposure at 0°C (10 knot wind). Although the evaporation of oil on ice in cold environments is slower, eventually the oil (even that covered by snow) evaporates to approximately the same degree as it would if spilled on the water in summer (Buist 2000). The limited available test data show that oil covered by snow continues to evaporate, albeit at a lower rate than oil directly exposed to air. The actual rate of evaporation is a complex function of a number of variables including snow diffusivity (related to the degree of packing), oil properties, air temperature, wind speed, and the thickness of the oiled layer.

Snow accumulates on another substrate so that, in practice, response planning considers both the snow layer and the underlying substrate of the shoreline.

DETECTION AND DELINEATION OF OIL IN SHORE ICE:

Surveys to delineate and document the presence of oil on the shore typically follow a systematic procedure that may involve an initial ground or air survey to locate and define the extent of the affected area followed by detailed ground surveys to delineate and describe the oiled locations and the oil distribution. Oil on the surface of a shoreline or on ice and snow is easily detectable and delineation is straightforward. The Shoreline Cleanup Assessment Technique (SCAT) is one method to detect and delineate oil on the shore and has been adapted for use in cold climates and on shorelines with ice and/or snow (Owens and Sergy 2004). This technique is based on a systematic survey design and the use of standard terms and definitions to create an information base for the response team to decide which shorelines should be cleaned and how cleanup end points can be achieved without incurring environmental damage. In particular, a set of standard terms define the basic categories of shore zone ice and snow conditions.

The detection and delineation of oil on the shore becomes significantly more difficult when oil:

- penetrates into or is buried by clean beach sediments,
- becomes incorporated within existing shore-fast ice and grounded floes,
- is covered by newly formed ice from the freezing of wave splash, spray, or swash,
- infiltrates into snow, or
- is covered and buried by wind-blown snow.

In these circumstances some or none of the oil may be visible at the surface. Typically, the search for subsurface oil involves a grid or other geometric pattern based on either working outwards from a source or from an observed surface oil patch (API 2013). Digging pits and trenches or core/tube sampling are labor intensive and very time consuming, especially in ice, so that portable ice drills or ice trenching devices are more efficient. Dogs have been used for many years to detect subsurface oil pipeline leaks (Oil and Gas 2006) and field trials have demonstrated that they can successfully and rapidly detect even small amounts of oil covered by

0.5 m of ice and snow (Buvik and Brandvik 2009, Dickins *et al.* 2010). Developing technologies such as ground-penetrating radar and nuclear magnetic resonance may provide improved tools in the future.

SHORELINE PROTECTION IN ICE-DOMINATED ENVIRONMENTS:

Shore Zone Resources at Risk, Sensitivity and Vulnerability

Sensitivity of resources at risk varies in time and space. Cold climate and ice-dominated coastal ecosystems range from productive salt marsh habitats to barren ice-scraped bedrock shores. Ice plays a particularly important role in the coastal ecosystem as it covers the otherwise potentially productive intertidal zone for parts of the year and mobile ice scours and scrapes organisms from hard surfaces.

Life in the shore zone becomes increasingly stressed as the length of winter increases and as temperatures decrease so that plants and animals avoid or have adapted to harsher conditions. This change is evident in salt marshes that show an impoverishment of species with increasing latitude and decreasing temperature (Walter 1977). In high arctic regions, such as Greenland, the Nunavat Islands, Spitzbergen and the new Siberian Islands, there may be only one or two associations of grasses, for example, *Pucinellia phryganodes*, and/or sedges, such as *Carex glareosa*. A second feature of arctic salt marshes is that the typical cross-shore zonation is replaced by an irregular mosaic of communities (Macdonald 1977).

Cold climate ice-dominated environments have shortened growing seasons. As summers shorten, so habitat use becomes more intense and the risk from spilled oil increases. By contrast the cold season is one of plant dormancy and often out-migration of birds and marine life.

Sensitivity and vulnerability must both be taken into consideration as a sensitive resource or species may be sensitive but not always vulnerable to spilled oil. Many resources are vulnerable as they are static, such as wetland habitats. Some mobile resources are more at risk than others because of their life style, water ducks are considerably more vulnerable as they spend most of the time sitting on the sea surface as compared to aerial hunters or scavengers, such as gannets or eagles. Another case in point is the rear-round outflow of fresh water from large rivers, such as the Lena, Mackenzie, Ob, Pechora and Yukon, that creates a convergence zone where fresh and ocean waters meet. It is well documented that oil cannot cross these zones so that oil transported down river may be trapped within the fresh-water body and not escape into the open ocean whereas, conversely, oil on the sea may be excluded from the coastal zone.

Protection Priorities

The establishment of response strategies and protection priorities involves evaluation of relative risk for those resources in a potential spill path. Many ice-dominated regions have well defined high-use habitats, such as deltas, wetlands, bird rookeries, and mammal haul outs, which can be easily identified and mapped. Pre-response planning may extend to the development of first response protection strategies, for example, at inlets or river mouths.

Protection Strategies

The primary response strategy in all oil spills is to recover or eliminate oil on water as close to the source as possible. The coastal zone is one of the more productive ecosystems and the fall back strategy if source or near-source control is not possible is nearshore protection to prevent oil reaching the shore or to minimize the effects of spilled oil shore zone resources a risk.

Response timing is very different at the end of the summer ice-free season as few resources are at risk and cleanup can be carried out in a planned, progressive manner over the winter months. By comparison, a spill towards the end of the ice-dominated winter leaves only a short window of opportunity to remove oil in the shore zone before seasonal ice melts or breaks up and the growing season or migrations begin.

SHORELINE CLEANUP IN ICE-DOMINATED ENVIRONMENTS

The Cleanup Decision Process

The first steps in the cleanup decision process involve the development of agreed cleanup priorities, strategies, the monitoring and inspection process and the end points so that everyone has the same goals and expectations. The shoreline response decision process in any environment includes:

A. Locating, delineating and describing the oil on the shore or ice,
B. Evaluating response priorities,
C. Determining the consequences of treatment strategies and tactics,
D. Estimating volumes and types of wastes generated by the response options,
E. Agreeing on treatment end points, and
F. Defining the sign-off process.

The decision process is rarely straightforward and balances environmental concerns, the needs of local communities, operational practicality, and safety (Baker 1997). Frequently trade-offs are necessary. For example, tundra shorelines are sensitive to trampling and vehicle traffic during the summer but oil removal or treatment may be considered critical to protect wildlife.

The development of shoreline cleanup strategies and priorities involves an understanding of the effects of the oil and the consequences and effects of the intended treatment activities themselves. Studies on the Net Environmental Benefit (NEB) of shoreline treatment have shown that inappropriate response actions can cause more harm than the oil alone and can delay rather than accelerate recovery (Baker 1995). This NEB concept is particularly important in ice-dominated cold climates where recovery would be expected to be slower and where vegetated tundra or wetland shorelines are highly susceptible to disturbance by human or vehicle traffic.

Shoreline Treatment Options

Treatment or cleanup tactics are determined to a large degree by the type and amount of oil and by the shoreline type. Shoreline treatment manuals have been prepared for the Arctic and ice-dominated, cold climate shorelines that summarize the accumulated experience to provide guidance for decision makers and planners: for example, the EPPR Field Guide for Oil Spill

Response in Arctic Waters (EPPR 1998). Table 1 is an example of a matrix developed for different oil types on inundated low-lying arctic tundra (Owens and Sergy 2010) (Figure 1C).

Table 1 Shoreline Treatment Options for Inundated Low-Lying Tundra

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Manual removal		▪	▪	▪	▪
Vacuums		■	■	■	
Vegetation cutting		▪	▪	▪	▪
Passive sorbents		▪	▪	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

To a large extent, the same strategies and tactics typical used in warmer environments apply equally to Arctic and cold-climate shorelines so that experiences gained and lessons learned can be applied in most situations. The primary differences relate to the presence of different shoreline types, in particular, ice and inundated tundra, and operational, safety, and logistics issued associated with remote areas and cold working environments. Only a few ice-dominated environments are in relatively densely populated areas, such as the Baltic Coasts and the Lower Great Lakes, the St. Lawrence Estuary and the southern Gulf of St. Lawrence in Canada.

The selection of cleanup options depends on the character of the shore zone so that response strategies and tactics must be modified when ice and/or snow are present; for example, a shore with permeable coarse sediments in warm months can be replaced by a frozen ice, impermeable substrate in cold conditions.

The recovery of oiled snow and ice can create a large volume of waste that contain only small amounts of oil and one option to minimize the waste stream is to melt and decant the ice or snow on site. The many individual tactics that can used to treat or clean shorelines can be grouped into three basic shoreline response strategies:

a. natural recovery without intervention
b. physical removal of oiled materials, and
c. *in situ* treatment of the stranded oil.

Natural cleaning is often the least damaging alternative for treating light and moderate oiling, particularly where access is limited or difficult, as is often the case in ice dominated environments. This strategy may be appropriate where:

- to treat or clean stranded oil may cause more (unacceptable) damage than leaving the environment to recovery naturally (NEB), or
- response techniques would not be able to accelerate natural recovery, or
- safety considerations could place response personnel in danger either from the oil (itself) or from environmental conditions (weather, access, hazards, etc.).

Physical removal involves the recovery and disposal of stranded oil. There are a range of tactical options to remove oil that basically involve either flushing or washing and recovery or manual or mechanical removal.

- Flooding and washing move oil either onto the adjacent water where it can be contained by booms and collected by skimmers, or towards a collection area, such as a lined sump or trench, where it can be removed by a vacuum system or skimmer. This strategy is slow and labor intensive but generates only liquid wastes.
- Manual removal includes shovels and rakes as well as cutting oiled vegetation and the deployment and recovery of passive sorbents to collect oil. Manual removal is slow and labor intensive, but generates less waste than mechanical removal.
- Mechanical removal techniques essentially use equipment designed for earth-moving or construction projects, although a few commercial devices have been fabricated specifically for shoreline cleanup applications. Although cleanup rates are less labor intensive and are much faster than manual removal, which may be factors in remote areas, as much as ten times more waste is generated by mechanical removal, which in itself may be a logistics issue.

The *in situ* options involve treatment that is conducted on-site and minimizes the generation or recovery of oiled waste materials that then must be transported and disposed (Owens *et al* 2009). *In situ* treatment is particularly suited for remote areas where logistics are a major factor in operational practicality and feasibility. The range of tactics includes:

- Mechanical mixing of oiled sediments (also known as tilling, land farming, or aeration),
- Sediment relocation (also known as berm relocation or surf washing),
- Burning of oiled logs or organic debris is commonly used as these contain very small amounts of oil, or
- A group of chemical or biological tactics involves the addition of agents to facilitate removal of the oil from the shore zone, or accelerate natural *in-situ* oil removal,

degradation and weathering processes. Bioremediation is a practical option (Prince *et al.* 2000) although biodegradation rates are slowed in cold climates by temperature and limited nutrient availability.

SUMMARY:

The character and role of ice on shorelines is well known. Research and experience over the past 40 years provide planners and responders with a good understanding of the fate and behavior of oil in Arctic and ice-dominated environments. The primary differences from warmer climates relate to the presence of different shoreline types, in particular, ice and inundated arctic tundra as well as the safety, and logistics issues associated with operations in remote areas and cold working environments.

Arctic and cold climate shoreline oil behavior and response options have been studied and tools and guidelines are in place to assist decision-makers, operations planners and cleanup workers. The potential challenges for a shoreline response in ice-dominated environments include:

- Extreme temperatures and weather (blizzards – whiteouts)
- Cold stress (equipment and people)
- Reduced efficiency
- Short days (in high latitudes)
- Greater logistics support required
- Drifting snow - potentially unstable ice
- Oil may be difficult to detect in snow or under ice
- Oil removal before it is remobilized by spring melt and/or breakup

Factors that influence strategies and tactics:

- Cold lowers viscosity – slows spreading
- Recovery of 100% of is possible if oil has spilled on ice and sorbed by snow
- Spreading and transport may be minimized so can recover oil before it is remobilized during spring thaw
- Potential operational impacts lower as fewer resources are at risk in winter months
- Evaporation is retarded.

Planning shoreline response strategies in ice-dominated environments cannot simply transpose summer or warm season procedures to cold or winter operations. Planning and training requires a different approach to safety, support and logistics and needs to consider and plan for a range of scenarios that include oil on, within or under a range of snow and solid and broken ice conditions.

REFERENCES:

API 2013. Subsurface Oil Detection and Delineation in Shoreline Sediments: Phase 1 – Final Report. API Technical Report 1149-1, Washington DC, 46 pp.

Baker, J.M., 1995. Net Environmental Benefit Analysis for Oil Spill Response. International Oil Spill Conference Proceedings, American Petroleum Institute, Washington DC, Pub. No. 4651, 611-614.

Baker, J.M. 1997. Differences in Risk Perception: How Clean is Clean ? Issue Paper prepared for the International Oil Spill Conference, American Petroleum Institute, Washington DC, Tech Report IOSC-006, 52 pp.

Bech, C. and Sveum, P. 1991. Spreading of Oil in Snow. Proc. 14th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Ottawa, ON, 57-71.

Belore, R.C. and Buist, I.A., 1988. Modeling of Oil Spills in Snow. Proc. 11th Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Ottawa, ON, 9-29.

Buist, I. 2000. In "Oil Spills in Ice Discussion Paper: A Review of Response Options, Ice Conditions, Oil Behavior and Monitoring". DF Dickins Associates Ltd., Vaudrey & Associates Inc., SL Ross Environmental Research Limited. Prepared for Alaska Clean Seas, Prudhoe Bay AK, 3-24.

Buvik, T and Brandvik, P. J., 2009. Using dogs to detect hidden oil in beach sediments. Results from field training on Svalbard, September 2008 and on the west coast of Norway (Fedje/Austerheim). November 2008. SINTEF F12274 Open Report, Report, Trondheim, Norway, 20 pp.

Carstens, T. and Sendstad, E. 1979. Oil Spill on the Shore of an Ice-covered Fjord in Spitsbergen. POAC 79, 5th Int. Conf. on Port and Ocean Engineering under Arctic Conditions Proceedings, 1227-1242.

Davies, J.L. 1972. Geographical Variation in Coastal Development, Oliver and Boyd, Edinburgh, 204 pp.

Dickins, D.F., Andersen, J.H., Brandvik, P.J., Singass, I., Buvik, T., Bradford, J. and Hall, R. 2010. Remote Sensing for the Oil in Ice Joint Industry Program 2007-2009. *Proceedings 33rd Arctic and Marine Oilspill Programme (AMOP) Technical Seminar,* Ottawa, ON 815-840.

EPPR 1998. Field Guide for Oil Spill Response in Arctic Waters. Environment Canada, Yellowknife, NT, Canada, 348 pp.

Forbes, D.L. and Syvitski, J.P.M. 1994. Paraglacial Coasts. In: Carter, R.W.G. and Woodroffe, C.D. (eds.) Coastal Evolution: Late Quaternary Shoreline Morphodynamics. University Press, Cambridge, 373-424.

Forbes, D.L. and Taylor, R.B. 1994. Ice in the Shore zone and the Geomorphology of Cold Coasts. Progress in Physical Geography, 18 (1): 59-89.

Hill, P.R. and Solomon, S. 1999. Geomorphic and Sedimentary Evolution of a Transgressive Thermokarst Coast, Mackenzie Delta Region, Canadian Beaufort Sea, Journal of Coastal Research, 15: 1011-1029.

Lauriol, B. and Gray, J.T. 1980. Processes Responsible for the concentration of Boulders in the Intertidal Zone in Leaf Basin, Ungava, In "The Coastline of Canada", (S.B. McCann, ed.), Geological Survey of Canada, Ottawa ON, Paper 80–110, 281-292.

MacDonald, K.B. 1977. Plant Communities of Pacific North American Salt Marshes. In. Chapman, V.J. (ed.) Ecosystems of the World – 1. Wet Coastal Ecosystems, Elsevier Scientific Pub. Co. Amsterdam, 167-191.

Mackay, D., Leinonen, P.J., Overall, J.C.K. and Wood, B.R. 1975. The Behaviour of Crude Oil in Snow. Arctic, 28(1): 9-22.

Oil and Gas, 2005. www.elitedetectiondogs.com/W9-17_Archive.pdf Summer 2005, p. 33-36

Owens, E.H., Dickins, D.F. and Sergy, G.A. 2005. The Behavior and Documentation of Oil Spilled on Snow- and Ice-Covered Shorelines". International Oil Spill Conference Proceedings, Amer. Petr. Institute Pub. No. I 4718B, Washington DC, 513-519.

Owens, E.H., and Harper, J.R. 1977. Frost table and thaw depth in the littoral zone near Peard Bay, Alaska. Arctic 30 (3): 154-168.

Owens, E.H. and Sergy, G.A. 2004. The Arctic SCAT Manual – A Field Guide to the Documentation of Oiled Shorelines in Arctic Regions. Environment Canada, Edmonton AB, 172 pp

Owens, E.H. and Sergy, G.A. 2010. A Field Guide to Oil Spill Response on Marine Shorelines. Environment Canada, Ottawa ON, Canada, 233 pp.

Owens, E.H., Taylor, E., O'Connell, K. and Smith, C., 2009. Waste Management Guidelines for Remote (Arctic) Regions. Proceedings 32nd Arctic and Marine Oilspill Programme (AMOP) Technical Seminar, Ottawa ON, 155-166.

Prince, R. C., Bare, R. E., Garrett, R. M., Grossman, M. J., Haith, C. E., Keim, L. G., Lee, K., Holtom, G. J., Lambert, P., Sergy, G. A., Owens, E. H., Guénette, C. C., 2000. Bioremediation of a marine oil spill in the Arctic. In *In situ bioremediation of Petroleum Hydrocarbon and other Organic Compounds.* (Alleman, B. C. and Leeson, A., Eds.) Battelle Press, Columbus, OH. pp. 227-232.

Rosen, P., 1979. Boulder barricades in central Labrador. Journal of Sedimentary Petrology, 49, 1113-1123

Sendstad, E., 1980. Accelerated biodegradation of crude oil on an Arctic shoreline. Proceedings 3rd Arctic and Marine Oilspill Programme (AMOP) Technical Seminar, Environment Canada, Ottawa ON, 402-416.

Sendstad, E. Sveum, O., Endal, L.J., Brattbakk, Y. and Ronning O. 1984. Studies on a seven years old seashore crude oil spill on Spitsbergen. Proceedings 7th Arctic and Marine Oilspill Programme (AMOP) Technical Seminar, Environment Canada, Ottawa ON, 60-74.

Walter, H., 1977. Climate. In. Chapman, V.J. (ed.) Ecosystems of the World – 1. Wet Coastal Ecosystems, Elsevier Scientific Pub. Co. Amsterdam, 61-67.