Meetings

Ist Symposium on the Geological Action of Drift Ice, Québec, Canada, April 20-24, 1974.

This symposium was held at the Complexe Scientifique, under the auspices of the Universite du Québec and the Institut National de la Recherche Scientifique. Abstracts submitted are published below and, in certain instances, abstracts available that were prepared in both French and English languages have been published in both versions.

Sedimentary Structures Related to the Influence of Drift Ice as Seen on the Shelf off Northern Alaska by PETER W. BARNES and ERK REIMNITZ, United States Geological Survey, Menlo Park, California.

It has been rediscovered that ice gouging is a significant agent influencing arctic sedimentation. Obviously, gouging should leave a record in the sediments. To date, no reports are known relating to the sedimentary structures that would result from the intense action of ice on arctic shelves. Drifting ice interacts with the surface sediments and currents of the Beaufort Sea shelf to form a series of morphologies and sedimentary structures that are related to water depth, ice type and distribution, and season of the year. Four shelf facies are defined. No analog for these structures is reported from the geologic record, however, several glacial-marine sections in the Pleistocene are prime candidates for investigation.

Inshore (2-10 m), river water drainage through strudel in the shore-fast ice scours the bottom during the spring, creating circular depressions rimmed by levee-like deposits. During the summer currents and drifting ice rework the sediments resulting in the development of ripples, sediment ponding in scour depressions, ice-gouge depressions and grooves and ice-plowed metastable sediment ridges.

Further seaward (10-25 m), but inside the shear line between shore-fast ice and pack ice (10-25 m), sediments are protected from extensive ice reworking. Horizontal layering of graded sandy silts interbedded with silty clays are common in the upper metre of sediment of this depth zone. Cross lamination is notably absent, but bioturbation is intense.

At midshelf (20-40 m), outside the shear line, ice-gouging creates large channel-like features. Benthic fauna is absent or patchy. Cores, photographs, seismic data, and diving observations in this zone display displaced blocks of sediment, slump features, disrupted layering, and an absence of small-scale bedding structures. These same data suggest a complete and total reworking of the Holocene section by ice-gouging.

The outer shelf (40-130 m) appears to have older ice-gouged and ice-rafted morphologic features. The disrupted relief is more often subdued; the benthic fauna is better developed, there is a fairly well defined surface gravel layer, and the near surface sediments are stratified.

Drift Ice Action in Late Paleozoic Glacial and Post-Glacial Sequences of Australia and South America by R.L. BOWEN, Department of Geology, University of Southern Mississippi, Hattiesburg, Mississippi.

Records of drift-ice action in marine and non-marine late Paleozoic sequences are common both in Australia and in the Parana Basin region of South America.

Non-marine sequences, frequently varved, have abundant occurrences of dropped stones, released from melting drift ice. These record persistence of cold climates and/or cold winters in periglacial areas. Far less common, but occasionally observed, are drift ice-plowing phenomena.

In marine sequences, both dropped stones and "nests" (presumably indicating sites where debris-laden drift ice sank after partial melting) occur with considerable frequency. These phenomena are not confined to deposits which are contemporaneous with recorded glacial action, but occur in sequences as well which may be as much as 10-20 million years younger than the latest indisputable glacial deposits. They appear to demonstrate that climatic conditions of the post-glacial times remained sufficiently rigorous, and that winter drift ice regularly formed in estuaries, bays, and protected seas of the Permian both in Australia and South America. In both regions, phenomena clearly associated with drift-ice action disappear by late Permian times. Debris transport by drift ice obviously indicates plucking, gouging, and related effects at the ice-shore margins, but such features have not yet been discovered and recorded.

Apparently, so long as unconsolidated terrestrial glacial debris remained as the superficial cover exposed to erosion and climates remained sufficiently cold for winter bay-ice formation, drift ice was an effective agent for the transport and distribution of large clasts over adjacent areas of contemporaneous sedimentation.

The Action of Ice and Frost in the Development of Moderate Climate Baltic Beaches by W. BROCHWICZ-LEWINSKI and S. RUDOWSKI, Institute of Geology, Warsaw University, Warsaw, Poland.

Ice occurs in the nearshore of the southern Baltic Sea for a period of 4 to 74 days per year. It remains longer on beaches than elsewhere, usually for 2 to 3 months a year, and beaches are frozen for about the same period, although numerous freeze-thaw cycles do occur. Such conditions favor the development of various structures related to ice and frost action, the most common being ice-pushed and ice-deposited ridges or mounds up to 2 m high, ice-rafted debris including boulders, ice-cemented blocks, frost cracks, beaches resting on ice or snow patches, buried ice lenses, solifluction features, and various features related to the melting of ice including shore-ice kettles.

Ice rafting of coarse debris is of interest, numerous boulders and pebbles from a known till deposit being transported 5 km from their source. The destructive action of ice masses is significant. Ice floes under wave and current motion commonly truncate the top of the underwater bars and build ridges when pushed on the shore. Subsequently abrasion of the beach results from this action of ice over submerged bars. Ice also influences the development of the beaches in stopping or impeding the action of normal shore processes (waves and currents), and in shifting the shoreline seawards. In the southern Baltic region shore ice often shifts the shoreline 400 to 500 m seawards.

The Baltic beach structures related to ice and frost action have small chances of preservation because of the prevailing dynamic conditions. However, their preservation in subfossil state is possible. It seems justified that the studies of southern Baltic beaches should take into account the above-ice and frost-made features for a reliable interpretation of sedimentary structures and composition of beach deposits.

Aspects de Neige et de Sable sur le Pied de Glace, Littoral est de la mer d'Hudson, Québec par ANDRÉ CAILLEAU, Centre d'Etudes Nordiques, Université Laval, Québec

Sur le rivage est de la mer d'Hudson, au Nouveau-Québec, à Poste-de-la-Baleine, par 55°17' Nord, 77°46' Ouest, (température moyenne annuelle -4,3°C), sur le pied de glace, ont été étudiés du 15 avril au 2 mai 1973 des formes et aspects principalement nivéo-éoliens (NIV = mélange de neige et sable apporté par le vent) comprenant des placages, des champs de cupules à fond rempli de sable, des pinacles de glaces résultant du regel de la neige (micro-pénitents?) des champs de sillons parallèles séparés par des bourrelets un peu inclinés, coiffés de sable NIV, et encore de minces plaques (1 à 3 mm) de glace transparente sous lesquelles la neige fond, et que parsèment de délicates fleurs de glace (givre?). Sur la banquise enneigée, on a recueilli du sable NIV jusqu'à 130 m du rivage; plus près de celui-ci et parallèlement à lui s'édifient un à trois remparts littoraux NIV, atteignant 100 à 300 cm de haut en mai. De la fin mai au début juin, la neige fondant ou se sublimant, le NIV prend la forme de champs de cônes pointus ou de mamelons doux. Entre la plage soulevée à Elymus et le premier rempart NIV, sur l'estran enneigé, les ruisselets de fonte déposent du sable, d'où un dépôt en partie nivéo-fluvial.

La variété de ces formes et processus tient aux états variés de la matière (solide, liquide, vapeur) comme c'est aussi le cas à une échelle beaucoup plus grandiose, pour la Terre, Mars et les autres planètes. Et ce sont surtout les changements d'état qui commandent les formes de tous ces corps, des plus petits aux plus grands.

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Outlook on Niveo-Eolian Forms and Deposits on an Icefoot, East Coast of Hudson Sea, Québec.

The Great Whale River settlement is located on the east coast of Hudson sea, in New-Quebec, 55°17'N, 77°46'W, (mean annual air temperature -4,3°C). On the icefoot from April 15th to May 2nd 1973, the following niveo-eoliam forms and deposits have been studied (niveo-eolian = NIV = mixed deposits of snow and wind-driven sand): sheets of sand-strewn cupules; ice-pinnacles resulting from snow-refreezing (micropenitents?); fields of parallel furrows and slightly deviated from the vertical small sand-capped ridges and thin (1-3 mm) plates of transparent ice, under which the snow is melting; tender ice-flowers (hoar-frost?) grow upon those plates. On the snow-covered packice, NIV sand was collected as far as 130 m from the shore. Near the shore, one to three NIV beach-ridges have been built up, reaching in May 100 to 300 cm in height. From the end of May to the beginning of June, as the snow melts away or sublimates, the NIV evolves into fields of sharp cones or soft rounded hillocks. Between the Elymus - covered raised beach- and the first NIV ridges, on the snow-covered shore, sand is deposited by melt-water streamlets, thus forming a partly niveo-fluvial deposit.

Such a variety of forms and processes is due to the varied states of the matter (solid, liquid, vapour), as is also the case, on a much larger scale, for the Earth, Mars and other Planets. Forms of all these features, from the smallest to the largest ones, are principally controlled by the changes of state of matter.

Les Dépôts Glacio-Marins Actuels de Anciens par LOUIS DANGEARD, Institut Océanographique, Paris Ve, France et JEAN-RENE VANNEY, Institut de Géographie, Université de Paris-Sorbonne, Paris Ve, France.

La communication se propose de définir et de caractériser la mise en place marine des matériaux transportés par les glaces de toutes origines. Le sédiment glacio-marin originel doit être fondamentalement distingué du glacio-marin occasionnel (exclu de cette étude) qui est constitué de matériaux abandonnés par les glaciers continentaux puis submergés et remaniés par les agents marins.

La première partie décrit les formations glacio-marines actuelles ou récentes qui nous sont présentement connues à partir des renseignements recueillis par prélèvements ou photographies sur les littoraux comme sur les fonds marins.

La charge sédimentaire véhiculée par les glaces procède de deux types de préhension: (1) les phénomènes glaciaires qui agissent sur ou sous le front marin des glaciers qui peuvent s'avancer en mer sous forme de plate-forme flottante d'où se détachent icebergs et îles de glace. Aux matériaux d'origine continentale sont adjoints des sédiments (détritiques ou biogènes) prélèves par râclage sur le fond de la mer; (2) les phénomènes glaciels, propres aux glaces de mer (banquette littorale, banquise littorale, saisonnière ou permanente) qui tiennent leur chargement: (a) de la saisie effectuée sur les rivages où elles se forment et séjournent; (b) de l'incorporation d'éléments fournis par les crues, les vents et les courants.

La décharge peut se faire sur place mais le plus souvent à des distances qui varient en fonction de la nature de l'agent de transport. Les modalités du dépôt invitent à distinguer: (1) le glacio-marin d'épandage, étalé en bordure des fronts glaciaires, au débouché des chenaux sous - glaciaires, sous les lignes de disjonction des icebergs, et sous les plates-formes flottantes; (2) le glacio-marin d'échouage engendré par les actions d'affouillement et de sédimentation produites par les glaces flottantes (banquises ou icebergs) drossées ou abandonnées à la côte; (3) le glacio-marin de délestage déterminé par la fonte progressive des glaces dérivantes qui abandonnent leur charge sous forme de semis discontinus, d'éssaims dispersés et de blocs isolés.

La seconde partie est consacrée à la revue des quatre grandes phases de l'histoire géologique caractérisées par leur efficience glacio-marine. (1) La phase plio-pléistocène a laissé d'abondantes traces rencontrées en surface en bordure des zones froides actuelles aussi bien qu'en profondeur (carottages) sous les latitudes tempérées. Ces revêtements et niveaux détritiques sont considérés comme des témoins climatiques qui ont permis des phases majeures et mineures d'exportation glacio-marine. Il ressort des travaux réalisés dans le nord de l'océan Pacifique et dans l'océan Austral que les dépôts glacio-marins paraissent avoir été plus abondants au début des périodes d'amélioration climatique (phase cataglaciaire) que pendant les crues glaciaires elles-mêmes. (2) Pendant le Permo-Trias les marges continentales du Gondwana en cours de disjonction furent périodiquement soumises aux oscillations glacio-eustatiques et aux accumulations de moraines et de blocs épars interstratifiés entre des horizons pélitiques parfois coquilliers. (3) A l'Ordovician terminal, sur le fond des mers épicontinentales occupant le Sahara et l'Europe actuels (Espagne, Normandie) des lits de formations glacio-marines s'intercalèrent entre de puissantes séries marines. (4) A la fin du Précambrien Eocambrien), en bordure des chaînes antécambriennes des blocs eurasiatique et austral, s'individualisèrent de vastes et profondes dépressions dont les marges étaient colonisées par des plates-formes flottantes et des banquises qui y abandonnèrent leurs dépôts caractéristiques.

Un essai de représentation cartographique des phénomènes glacio-marins, actuels et fossiles, illustre et résume les divers aspects exposés au cours de cette communication.

Modern and Ancient Glacio-Marine Deposits

The paper defines glacio-marine sediments and gives characteristics of their modes of deposition in the sea by all kinds of ice. True glacio-marine deposits, i.e. sediments deposited by ice in the sea should be distinguished from pseudo-glacio-marine deposits (excluded from this study) which consists of material abandoned by the continental glaciers, then submerged and reworked by marine agents.

Ancient and modern glacio-marine deposits as known from dredging, coring, undersea photographs, and exposures are described in the first part. Sediments deposited by ice have two origins: glacial and "glaciel". The first category includes sediments from ice shelves, icebergs, and ice islands. Generally a large amount of these sediments came from the continents while a variable proportion is composed of detrital and biodetrital sediments picked-up or grasped on sea floors. The second category includes sea ice-born sediments (shore and pack ice) which are usually grasped on shores or brought over pack ice by wind or rivers discharging their load over ice before the break-up.

Dispersion of sediments by drift ice varies greatly and may influence the type of deposit. It is then necessary to distinguish between 1) proximal glacio-marine deposits spread out in front of glaciers, at the outlet of subglacial channels, in the zone of iceberg calving, and under ice shelves; 2) distal glacio-marine deposits, which can be divided into two categories: a) those related to the effects of grounding floes and icebergs; b) those resulting from the gradual melting of drift ice and the scattering of their load over a large area.

A review of the four main geological periods characterized by glacio-marine action is made in the second part. (1) The Plio-Pleistocene period. Evidences of glacio-marine action are numerous during this period. Glacio-marine sediments are widespread at the surface of the sea floor in cold regions (Arctic and Antarctic), and are also found buried under recent sediments in middle-latitude regions having today a temperate climate. It is evident from investigations made in the North Pacific and the Antarctic oceans that glacio-marine sedimentation reached a maximum at the beginning of each warming climate periods (cata-glacial phases) instead of during the main glacial periods properly. (2) The Permo-Trias. During the Permo-Trias, expanding continental shelves of the Gondwana were the loci of glacio-eustatic oscillations, of drift deposits and erratics scattered throughout layered pelitic sequences occasionally fossiliferous. (3) The Upper Ordovician. Glacio-marine sediments are found in marine sequences deposited in epicontinental seas in North Africa (Sahara) and Europe (Spain, France), at the end of the Ordovician period. (4) The late-Precambrian. Glacio-marine sediments are also found in rock sequences of Precambrian age in North Africa and elsewhere.

A map showing the geographic distribution of ancient and modern glacio-marine sediments and features has been constructed, and will serve to summarize the various questions arising from this paper.

(Free translation)

Ice Effects on Coastal Sedimentation: Marine and Non Marine Examples by RICHARD A. DAVIS, Geology Department, University of South Florida, Tampa, Florida; VICTOR GOLDSMITH and YVONNE E. GOLDSMITH, Virginia Institute of Marine Science, Gloucester Point, Virginia.

Although the beach and nearshore zone is one of the most dynamic of all sedimentary environments it may be rendered essentially static by coastal ice formation. The non-tidal eastern Lake Michigan coast and the mesotidal coast of Massachusetts are compared to provide a possible spectrum of effects within the north temperate climatic zone. Both areas are dominated by severe onshore-moving storms during winter months.

Beginning in October the eastern coast of Lake Michigan is battered by intense storms as low pressure systems move across the Great Lakes region. Sometime in December temperatures are low enough to freeze the saturated sand beach. Large waves may lift slabs of the frozen beach and transport them in the littoral drift. A thin layer of ice forms when cold temperatures coincide with calm water conditions. This may range from slush to firm ice, up to several inches thick. Subsequent storms break up ice and concentrate it in ridges of en-echelon ice slabs on the beach and over the crests of long-shore sand bars. These ridges prevent any waves, and hence any physical energy, from reaching the beach.

The situation prevails from the latter part of December to early March. At this time snow and ice are melted from the beach. Melting on the ice-ridge surfaces concentrates incorporated sediment to the extent that the ridges are covered with a veneer of sand. The thin ice sheet between ridges melts producing open water. At this stage the strand-line area is open and irregular but "zero-energy" conditions prevail. Commonly small anti-clinal ice-push features and poor sediment sorting are present due to the "bulldozer" effect of ice.

A spring storm is generally responsible for the breakup and removal of the ice ridges. This permits waves to reach the beach, and normal beach processes once again result after a two- to three-month hiatus. The sorting and smoothing of the beach takes place in a short period of time, usually less than a day.

A similar spectrum of effects has been observed along the mesotidal marine coast of Massachusetts, with some variations between the two sides of the barrier islands: the exposed high energy ocean shoreline. On the ocean side of the barrier, winter freezing of the beaches acts as a stabilizing influence during the onslaught of the most severe storms of the year. Slabs of frozen beach are often transported large distances, both alongshore and inshore, encouraging environmental mixing of sediment.

On the estuarine side of the barrier islands en-echelon ice slabs up to 30 cm thick and 8 m long are pushed by the tidal currents into piles up to 3 m high at the high-tide line and on the supra-tidal barrier flats. These ice slabs, which are transported in and out of the marsh creeks by the semi-dirunal tidal currents, move significant amounts of *Spartina alterniflora* peat blocks onto the wide low-gradient and low-energy intertidal zone. Here, many of the peat blocks take root, encouraging the growth, both horizontally and vertically, of the leeside of these barrier islands while concomittant erosion occurs on the high energy side of the barriers. Any evidence of the effects of ice, such as striations, grooves and destroyed internal structures, is quickly removed after melting through sediment reworking by the much more dynamic wave and tidal processes.

Thus, despite the visually dramatic nature and extent of these ice effects along both the non-marine and marine coasts of the north temperate zone they essentially have only a static to slightly accretional effect on coastal sedimentary processes. With the melting of the ice, little sedimentological evidence remains of the ice as a geologic agent, except for some environmental mixing of sediment.

L'Action Géologique des Glaces dans l'Estuaire du Saint-Laurent par JEAN-CLAUDE DIONNE, Environnement Canada, Québec.

Les glaces jouent un rôle morpho-sédimentologic important dans l'estuaire du Saint-Laurent en étant à la fois un agent efficace d'érosion, de transport, de sedimentation et de protection. Chaque année des millions de tonnes de sédiments sont prélevés et déplacés par les glaces. Les zones intertidales sont particulièrement affectées par l'action des glaces qui tantôt érodent les fonds meubles tantôt abandonnent de grades quantités de débris de lithologie et de granulométrie variées allant de l'argile aux gros blocs de plus d'un mètre de diamètre. Les schorres et les slikkes sont profondément perturbées par les glaces flottantes; on y trouve notamment diverses marques d'érosion linéaires et circulaires et une grande abondance d'éléments grossiers. Par contre, les rivages rocheux ne portent que des marques mineures de l'action glacielle.

Documentation photographique sur l'action géologique des glaces dans l'estuaire du Saint-Laurent.

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The Geological Action of Ice in the St. Lawrence Estuary.

Drift ice is an important agent of erosion, transportation, sedimentation, and protection in the St. Lawrence Estuary. Millions of tons of sediments are displaced annually by ice while shores and bottoms are eroded. Ice has minor effects on beaches; local ice-push and minor features related to the melting of buried ice are observed; however beaches are a zone where large amounts of coarse sediments are incorporated into the ice before being carried elsewhere at breakup. The intertidal zones are more severely affected by ice which scours or scratches soft bottoms, and brings large quantities of sediments of various sizes and lithologies. Tidal flats and marshes are probably the more severely disturbed zones along the St. Lawrence Estuary. Marshes are characterized by a large amount of erratics up to boulders 2-3 m in diameter, and by ice-made pans, while various ice-made features occur in mud tidal flats such as grooves up to 2 km long, striations, hummocky micro-reliefs, mud ridges, polygonal patterns, ribbed grooves, ice-rafted debris, and other minor features. Rocky shores are only slightly modified by ice which scratches soft rocks and aids levelling the surface of shore platforms. A photographic documentation on the geological action of drift ice in the St. Lawrence Estuary is provided.

Le Glaciel de la Région du Chissibi, Baie-de-James, Québec Subarctique par JEAN-CLAUDE DIONNE, Environnement Canada, Québec.

Dans la région du Chissibi (ou de la Grande) dans les territoires de la Baie-de-James, soit entre le 53° et le 54° de latitude N. et le 71° et le 79°15' de longitude O., le glaciel fait partie de la morphologie de détail mais se révèle relativement important du point de vue sédimentologique. On le rencontre dans trois milieux: marin, fluvial et lacustre.

Le glaciel littoral-marin comprend diverses marques d'érosion dans les zones intertidales: rainures, cuvettes, bourrelets vaseux et autres marques d'affouillement; des champs de cailloux à la surface de la vase et de l'argile marine; des schorres à blocs et à marelles; des cordons de blocs; des cuvettes d'affaissement à l'emplacement de lentilles ou de radeaux de glace enfouis qui ont fondus tardivement; des injections per ascensum d'argile marine sous le poids des radeaux de glace; des volcans de boue miniatures et des réseaux polygonaux de rides argileuses.

Le glaciel fluviatile comprend des levées de blocs ou de gravier atteignant jusqu'à 5 m de hauteur au-dessus du niveau estival de la rivière; des cailloux épars sur les plages de sable et les basses terrasses limono-argileuses; des îlots de débris minéraux et organiques abandonnés par des radeaux de glace, lors de la débâcle, sur les basses terrasses jusqu'à une hauteur de 5 m; des cicatrices d'arrachement du tapis végétal et minéral à la surface des basses terrasses; des trocs d'arbre renversés et cassés et des tapis d'aulnes couchés au sol ou arrachés; des chaos sableux ainsi que des kettles ou trous de fonte dans un petit delta limono-sableux.

Le glaciel lacustre comprend des levées de blocs de 2-3 m de hauteur dues à l'expansion thermique de la glace; de larges et longues rainures sur le fond résultant du déplacement de blocs poussés vers la rive par les glaces; et des blocs épars abandonnés sur diverses plages sableuses reposant sur argile.

Les processus glaciels sont particulièrement actifs sur le littoral actuel de la baie de James en dépit de la faible amplitude de la marée (maximum de 2 m) et le long des rives du secteur aval du Chissibi où ils sont liés à la débâcle printanière qui par endroits élève le niveau de la rivière d'au moins 5 m. La majorité des formes glacielles n'est pas détruite au cours de l'inter-glaciel. Les glaces flottantes se révèlent un agent important d'érosion, de transport et de sédimentation dans la région du Chissibi, au Québec subarctique.

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Drift Ice Features in the Chissibi River Area, James Bay, Subarctic Québec.

From a morph-sedimentological point of view, ice-made features are relatively important in the Chissibi River area, in James Bay Territories, between latitudes N. 53° and 54°, and longitudes W. 71° and 79°15', an area having a mean annual air temperature of -3.5°C. They are found in three sedimentary environments: marine, fluvial, and lacustrine.

Ice-made features in the marine environment include erosional features in the tidal flats such as grooves, shallow depressions, mud ridges and other drag marks; boulder-strewn mud and clay flats; boulder-strewn marshes with ice-made pans; boulder ridges; large and shallow ice-melted depressions locating sites of buried ice cakes or ice cores; marine clay injected upward under pressures exerted by the load of ice cakes; miniature mud volcanoes, and polygonal patterns of mud ridges.

Ice-made features in the fluvial environment include ice-push boulder and gravel ridges up to 5 m high; boulders scattered at the surface of sand beaches and low silt-clay terraces; patches of mineral and organic debris pushed, during breakup, up to 5 m or more above mean river level; erosional scars at the surface of low terraces along the river; numerous broken and overthrown tree trunks, and a cover of crushed and uprooted *Alnus* on the low terraces; sand mounds and depressions, and kettles at the surface of a small silty-sand alluvial cone.

Ice-made features in the lacustrine environment include ice-push boulder ridges, 2-3 m high, resulting from ice thermal expansion; long and wide grooves on lake bottoms made by boulders pushed shoreward by ice; and scattered boulders on sand beaches overlying clay.

Drift ice processes are particularly active in the tidal flats of James Bay, although a small tidal range (maximum 2 m), and along the shores of the lower Chissibi River. Most ice-made features are not destroyed during the summer. Drift ice is considered an important agent of erosion, transport and sedimentation in the Chissibi River area, subarctic Québec.

Modeling of Backshore Slope Processes, South Shore of Lake Superior by JEFF DOZIER, Department of Geography, California State University, Hayward, California and JAMES MITCHELL and WILLIAM M. MARSH, Department of Geography, University of Michigan-Flint, Flint, Michigan.

The icefoot along the shore of Lake Superior and other Great Lakes influences the backshore slope processes by preventing waves from reaching the slope during the high energy season. A theoretical time-depth model of frost penetration on the backshore slope can be developed from equilibrium temperature theory. Two important variables in equilibrium temperature theory, wind velocity and soil moisture content, are also derived from physical considerations. Frost penetration increases with distance up the slope, and date of melt is later high on the slope than near the bottom.

Prediction of mass-wasting rates from the frost penetration simulation is only qualitative at this time, but this would be an interesting topic for investigation. Mass-wasting rates are greatest in the spring, when recently melted soil is nearly saturated. Only toward the end of spring does the icefoot melt away, and after this time the high energy winds and waves are seldom present. Not until late fall, before the icefoot has reformed, does sediment transport away from the backshore slope and along the shore appear to be at its annual maximum.

Ice Cusp Formation on Lake Superior Icefoots by JEFF DOZIER, Department of Geography, California State University, Hayward, California; BRUCE D. MARSH, Department of Geology and Geophysics, University of California, and WILLIAM M. MARSH, Department of Geography, University of Michigan-Flint, Flint, Michigan.

The genesis and evolution of the wavy lakeward edge of Lake Superior icefoots, along straight, sandy beaches, is examined. In the initial stages, the boundary between the impinging waves and the icefoot may be straight and nonperiodic. As the ice interface develops, the impinging waves, up to a certain energy level, produce an undulating interface through destruction at embayments and construction at promontories. Beyond this energy level, gross promontory destruction occurs. A complete analytical description of the energy transfer between the impinging waves and the ice-ridge front, leading to the formation of the undulatory ice front, is exceedingly difficult, if not impossible to construct. However, this interaction can be approximated as a linear system, whereby the wave energy is transferred to the ice ridge in the shallow-water transition region by convolution with a bulk transfer function representing the entire geomorphic process. Since the output of such a process is essentially represented by the geometry of the ice interface and the input is known from the impinging wave characteristics, a transfer function may be derived. The transfer function is found by taking the Fourier transform of the impinging wave forms and of the wavy interface geometry, and dividing the latter by the former and performing Fourier inversion on this quotient. A group of such transfer functions, for various wave spectra, are presented. These functions alone are ambiguous as they contain a good deal of information concerning nearshore transport processes. However, a further reduction of the transfer function is attempted by comparison with an analytical solution representing oblique wave refraction patterns over a stepped bottom topography and usual beach-cusp development. Conclusions are drawn from the transfer function regarding the relation between the physical instability of the initial ice front and conditions of icefoot development.

Pleistocene Marine Shore Platforms Eroded by Drift-ice by RHODES W. FAIRBRIDGE, Department of Geology, Columbia University, New York.

Large erratic boulders believed to have been transported by sea ice are widespread along the mid-Pleistocene emerged shore platforms of northwestern Europe. Late Pleistocene boulder accumulations are commonly found near the margin of the continental shelf. The anomalous, higher elevation of the earlier deposits is attributed to secular lowering of sea level due to plate tectonics.

The erratics are associated with so-called "wave-cut" marine abrasion platforms that are often carved in hard rock such as would require excessive periods of time for erosion by normal wave action. Dionne's invaluable research into drift-ice erosion provides an effective mechanism for explaining this intertidal abrasion. A similar drift-ice explanation is offered to account also for flat-floored stream beds cut into bedrock in mid- to high-latitude areas.

Finally, iceberg scours mark the Continental Shelf both of today and of the Ordovician Saharan glaciation; they are compared with the shore platforms scours, and found to be quite distinctive.

La Famille du mot "Glaciel" par LOUIS-EDMOND HAMELIN, Centre d'Etudes Nordiques, Université Laval, Québec.

L'agitation du Québec se connaît également au plan de la néologie, qu'il faut bien se garder de confondre avec la joualisation. En réponse à des besoins non satisfaits par les langues internationales, le Québec est entré dans certains champs de l'onomastique scientifique, notamment en ce qui concerne des faits de pays froids.

"Glaciel" est un neologisme de composition, créé en 1959, pour expirmer tout ce qui concerne les glaces flottantes et à tous les points de vue. Le glaciel, matière de recherches, favorise l'organisation des connaissances et permet une amélioration du savoir.

Glaciel a servi de tronc dans le dérivation systématique d'expressions pouvant mieux rendre des phénomènes connus ou exprimer le rèsultat de nouvelles recherches. Parmi les satellites, des mots dérivés (glacielle; glaciellisation) ou composés (interglaciel; fini-glaciel; fluvio-glaciel) De plus, des termes associés, soit comme adjectifs, tel glaciel lacustre (J.C. Dionne), soit comme substantifs: bourrelet glaciel, faciès glaciel, strie glacielle. Ainsi, glaciel permet d'utiliser à un autre point de vue le vocabulaire courant et celui de certaines disciplines.

L'ensemble du langage glaciel compose un outil commode, systématique et parallèle à celui d'autres domaines des connaissances. Il a contribué à concentrer la terminologie générale des glaces flottantes autour d'un terme de base permettant le provignement. Glaciel qui s'est rapidement répandu commence à être employé comme tel en anglais, en russe et en d'autres langues.

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The Word "Glaciel" and its Related Terminology.

This paper deals with the French terminology related to drift ice. The work glaciel created in 1959 to express every aspect dealing with drift or floating ice is now officially accepted in French, and occasionally used as such in English and Russian. It is a useful word pending to glacial (glacier ice). Numerous compound nouns and expressions are derived from it, and since a few years the vocabulary of drift ice has considerably increased.

(Free translation)

The Effects of Ice on the Beach and Nearshore, Point Barrow, Arctic Alaska by JAMES D. HUME, Department of Geology, Tufts University, Medford, Massachusetts and MARSHALL SCHALK, Department of

Geology, Smith College, Northampton, Massachusetts.

Annual longshore transport at Barrow is approximately 8000 cubic metres, about 3% of that found in topographically similar temperate areas. Storms control the rate of erosion of shorelines made of coarse sediments; melting and wave action, that of shorelines composed of silts and clays. The presence of ice in and on the beach and offshore protects and shapes the beaches, and adds by ice-shove up to a maximum of 10% to the sediment above sea level. Ice buckling results in depressions in the beach and offshore bottom up to 3 m deep. Arctic lagoons formed by barrier-island chains show a seasonal cycle of salinity ranging from about 28% in late summer to a probable 100% in spring, to 1% in early summer.

Winter Ice Conditions in a Macrotidal Environment, Cobequid Bay, Bay of Fundy, Nova Scotia by JOHN R. KNIGHT and ROBERT W. DALRYMPLE, Department of Geology, McMaster University, Hamilton, Ontario.

From January to early April, much of Cobequid Bay is covered with floating ice cakes which are dispersed by tidal currents and wind. Shorefast ice ranging up to 4 m in thickness occurs at the high-water line. From field observations made on the south shore in late February, 1973, it was observed that most of the intertidal zone sediments were frozen to a depth of several centimetres and that the depth of freezing was related to the sediment grain size (sandy areas 1-2 Ø) frozen to depths of 20 cm; and muddy areas frozen to depths generally less than 10 cm).

The falling tide deposited medium to thick ice cakes along the foreshore and on the intertidal sand bars, particularly when the wind direction had a northerly component. The grounded ice cakes picked up great quantities of sediment, including gravel and boulders, and over (sic) isolated areas removed the frozen crust covering the intertidal areas. In sandy areas where the frozen crust had been removed by ice-rafting or broken through by late-stage ebb flow, rapid local erosion took place by undercutting and scouring of the underlying unfrozen sediments to depths generally not exceeding 100 cm. In mud-flat areas, ice rafting of the frozen sediment crust left distinctive abrupt-sided depressions several metres across.

Ice grooving was observed only in the upper part of the intertidal zone in muddy sediments. The depth of grooving was limited by the frozen sediment crust.

The frozen surface of the intertidal zone essentially immobilized the movement of sediment by bedload and prevented the development of bedforms. This, together with floating ice which damped out wave action and the protection of the shoreline by shorefast ice may substantially curtail the effectiveness of winter waves and currents in moulding this macrotidal environment to any major extent.

Champs de Blocs Glaciels, Actuels et Anciens, au Golfe de Richmon, Nouveau-Quebec par DANIEL LAGAREC, Centre d'Etudes Nordiques, Universite Laval, Québec.

On trouve dans la région du golfe de Richmond, au Nouveau-Québec (56°15' lat. N., 76°30' long. O.), de nombreux champs de blocs à la fois sur le littoral actuel et les anciens rivages étagés de la mer de Tyrrell. Cette région est située dans la zone de contact entre les roches de la couverture protérozoiques (grès, dolomie, basalte et andésite) et celles du socle archéen (granite et gneiss). Au Quaternaire, elle fut recouverte par les glaciers, notamment par l'inlandsis laurentidien, et submergée ensuite jusqu'à une altitude de 260-270 m par les eaux de la mer de Tyrrell avant d'être soumise à l'action des processus périglaciaires.

On connaît au moins quatre origines possibles des champs de blocs dans les régions froides: glaciaire (blocs abandonnés par les glaciers et lessivés par la suite par les eaux fluviales, lacustres ou marines); périglaciaire (blocs provenant de la gélifraction et mis en place par des processus de solifluxion); glacielle (blocs apportés et concentrés par les glaces flottantes); résiduelle (blocs provenant de l'altération sur place, i.e. de la désagrégation en boule des granites et des basaltes). Des critères morphologiques et lithologiques permettent d'affirmer que les champs de blocs de la région du golfe de Richmond résultent principalement de l'action des glaces flottantes bien que d'autres processus aient pu jouer un rôle quelconque dans leur formation.

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Ancient and Modern Ice-made Boulder Fields, Richmond Gulf Area, Nouveau-Québec.

Numerous boulder fields occur on ancient and modern shorelines of the Richmond Gulf area, Nouveau-Québec (56°15'N; 76°30'W.). The area studied is located at the contact between the Archean crystalline shield (granite and gneiss) and the Proterozoic sedimentary (sandstone and dolostone) and volcanic (basalt and andesite) rocks of the overlying cover. Glaciers have overflowed the area during the Quaternary, and the Laurentides ice sheet is the last one to have flowed in a general direction, east to west. Marine submergence (Tyrrell Sea) followed the melting of glaciers and reached elevations up to 260-270 m, before the area was isostatically uplifted and surface exposed to periglacial processes.

At least four origins are known to explain boulder fields of cold regions: glacial (i.e. erratics transported and left by glacier ice, or till washed by running water or waves, marine or lacustrine); periglacial (i.e. frost-shatter boulders, frost-heaving, and solifluction processes); "glaciel" (i.e. boulders brought and deposited by drift ice); residual (i.e. boulders formed in situ by weathering processes). Morphological and lithological evidences from field observations strongly suggest that boulder fields in the Richmond Gulf area are mainly shore features related to drift ice action even though other processes may have contributed to their formation.

The Effects of Ice in the Littoral Zone of the Southern Gulf of St. Lawrence by E.H. OWENS, Atlantic Geoscience Centre, Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

This paper reports the results of a study undertaken during the winter of 1973/74 at Richibucto Head, New Brunswick, to monitor the character and effects of ice in the littoral zone. Bi-weekly profiles along a 250-m section of beach provide a record of morphological changes from November to April. These data are supplemented by temperature measurements, nearshore bottom profiles, and sediment-size analyses in order to determine the effects of ice on the shore-zone morphology and sediments. Studies of coastal processes and of barrier islands in the southern Gulf of St. Lawrence must include some consideration of the role of ice. Wave action is restricted for up to four months in each year by sea-ice, and ice is present on the beach itself for at least three months each year.

The results of the investigation reported in this paper will be related to seasonal variations in littoral-zone processes in order to present an assessment of the effects of ice on beach processes and coastal morphology.

Ice Scour Marks on the Sea Bottom off Northern and Eastern Canada by B.R. PELLETIER and I.M. HARRIS, Atlantic Geoscience Centre, Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

Sidescan sonar and conventional depth-sounding provide imaginary which indicates the widespread occurrence of marks on the sea bottom (formed by icebergs and pack ice running aground) off northern and eastern Canada. The marks typically have the form of linear furrows (troughs bordered by raised shoulders). Those that occur in the Arctic range in relief up to 10 m, in width from a few metres to serveral tens of metres, and in length up to 8 km. Those that occur in the eastern Canada offshore tend to be larger, as shown by their maximum observed dimensions (relief 10 m, width 250 m, and length 17 km). In the Arctic, the marks occur abundantly in depths of water up to 50 m. At greater depths the frequency of occurrence decreases, with no marks observed at depths greater than 75 m. In the eastern offshore region the marks are locally abundant in depths of water up to 400 m, and they occur to a maximum depth of at least 650 m. The deepest of these may be relic features formed during the Pleistocene lowering of sea level. The majority of the marks occur singly, but families or groups of parallel marks are fairly common in the Arctic. The Arctic occurrences are formed for the most part by the ploughing action of pressure-related structures in pack ice, whereas those off eastern Canada are formed primarily by bottom-dragging icebergs.

Ice Action Experiments on the Seashore, Southern Finland by HANNU MANSIKKANIEMI, Department of Geography, University of Joensuu, SF-80130 Joensuu, Finland.

The work describes how ice action on different kinds of shores has been studied by means of experiments. The study areas are at Pyhtää, southeast Finland, on the Gulf of Finland, and Seili, in the Turku Archipelago, on the Baltic Sea.

The observations made at Pyhtää are a continuation of work carried out there in 1968. In order to determine how the ice acts, 16 boulders (Ø 20-40 cm) were placed on an even rock plane (rapakivi) in 1971. Its height above sealevel is ± 0.0 m. In the course of the winter the boulders were moved 6-10 m landwards and forced up on the stony shore. At the same time the order in which they had been placed changed so that the paths followed by the boulders criss-crossed each other. In the winter of 1972-73 a similar experiment was carried out with six larger boulders (the largest was 132 x 74 x 55 cm and the smallest 35 x 33 x 23 cm) but, because of the exceptionally warm weather that winter, ice action was extremely weak. Only the smallest of the boulders were moved. The experiment will be continued during the winter 1973-74. Stony shores in the area have also been studied since 1969 with the aid of photography. The changes that have occurred have been small.

In the Seili area ice action has been studied on three islands, Seili, Ominainen and Orhisaari. Boulders 20-40 cm in diameter were placed along the waterline at several points on shores where the size of the stones varies between 6 and 30 cm. They were placed so that they followed the line of the shore. In the winter 1971-72 the changes that occurred were quite large. Some of the boulders were moved 50 to 200 cm landwards, some were moved along the shore several metres and some were moved seawards 100 to 200 cm. About a fifth of the stones disappeared completely. They were floated on ice floes either out into deeper water or to other shores. Some of them may also have been buried in gravel. The gravel of the shores was considerably chafed by the action of the ice during the winter. A number of 20-40 cm boulders were also placed on sandy shores in sheltered inlets. These were noted to have moved slightly both landwards and seawards. During the winter of 1972-73 ice action was weak. The experiments have been continued during the winter of 1973-74. Annual changes along the shores under completely "natural" conditions have also been observed at Seili with the aid of photography.

Ground and Aerial Imagery of Lake Superior Coastal Ice by WILLIAM M. MARSH AND MERWYN L. BRYAN, Department of Physical Geography, University of Michigan-Flint, Flint, Michigan; and JEFF DOZIER, Department of Geography, California State University, Hayward, California.

Field studies show that coastal ice on Lake Superior undergoes rapid structural and distributional changes over the course of the winter. Direct measurements of ice features and related processes are logistically difficult and hazardous, especially during the early winter formational period. Photographic remote sensing from the air and the ground provides a reliable source of primary and supplemental data and information. In addition to morphometric data, icefoot photographs are also a source of information on sediment distribution based on photographic tonal variations. For large segments of coastline, low altitude sensors such as side-looking radars as well as high-altitude sensors such as ERTS satellite multispectral scanners are a useful source of ice distributional data.

Some Aspects of Ice Action on the Barrier Island Shorelines of the Southern Gulf of St. Lawrence by S.B. McCANN and J.W. ARMON, Department of Geography, McMaster University, Hamilton, Ontario.

Ice is present in the southern Gulf of St. Lawrence for at least four months each year and has a number of distinct effects on coastal processes and morphology. The most important is the negative or inhibitive one, whereby wave generation is prevented or severely reduced by the presence of pack ice offshore, and wave action on the beaches is prevented by the presence of a wide band of fast ice. The positive effects, resulting from the formation of ice ramparts, ice push or scour, and ice rafting, are conspicuous on both the open and lagoonal beaches in spring, though not so pronounced as in the St. Lawrence Estuary or the Minas Basin. The full resumption of normal wave processes on the beaches in late spring and early summer tends to obliterate quite rapidly the effects of drift-ice action. Of particular interest in this area of low tidal ranges are the effects of drift and fast ice on the operation of the series of tidal inlets which interrupt the barrier island shorelines, and the degree to which lagoonal circulation of the tidal prism is dampened.

The paper is presented in two parts. The first, concerning the positive effects of drift ice, is based on field observations at Kouchibouguac Bay, New Brunswick, and on the north coast of Prince Edward Island in the late spring-early summer periods, 1971-73, and at the period of maximum ice conditions in February, 1973. The second, concerning the effects of ice on the tidal inlets and lagoons, is based on an analysis of four sets of high-altitude photographs covering most of the barrier island systems, which were taken on two occasions during each of the ice seasons, 1972 and 1973.

L'Action des Glaces Flottantes sur le Littoral et les Fonds Sous-marins du Spitsberg Central et nord-occidental par ANNIK MOIGN, Département de Géographie, Université de Bretagne Occidentale, Brest, France.

Bien que des mesures systématiques échelonnées sur une période assez longeu fassent défaut, la part des processus glaciels a pu être évaluée dans le façonnement d'une côte qui tend à redevenir azonale chaque été. Des plongées sous-marines ont permis de découvrir des microformes qui échappaient à l'énregistrement par écho-sondeur.

Les icebergs sont de dimensions variées mais toujours petits; ils se détachent de fronts glaciaires non flottants qui peuvent atteindre une cinquantaine de mètres au-dessus du niveau de la mer et, au plus, une cinquantaine de mètres au dessous. La partie immergée des icebergs, rongee d'un dédale de grottes et se terminant par une ou plusieurs racines effilées, adhère mal aux fonds sous-marins. Le rôle érosif se limite au creusement de sillons sur les versants de fjords et de cuvettes sur les plateformes. Ces microformes n'existent que sur fonds d'argile et disparaissent en dessous de 30 mètres en raison des dimensions réduites des icebergs. Le rôle de transport et de sédimentation n'est pas négligeable mais concerne uniquement les matériaux morainiques que le glacier peut transporter. Aucune prise en charge des sédiments des fonds sous-marins n'a été observée. Le rôle des icebergs est limité dans l'espace (versants de fjords et strandflats de rives de fjords). Dès qu'ils sortent des fjords, ils se fragmentent et fondent sour l'effet des vagues et de la tiédeur du courant Nord-Atlantique.

La banquise subit en juin une débâcle très rapide. En quelques jours les radeaux de glace s'éloignent de la côte et fondent dans le courant Nord-Atlantique. Aucun empilement côtier n'a encore été observé. Le rôle érosif de la glace de mer semble nul sur les fonds sous-marins. Il est également nul sur le littoral, occupé par le pied de glace avant l'installation de la banquise et après sa disparition.

Le rôle du pied de glace est analysé suivant son type (pied de glace de falaise suspendu, pied de glace de plage ou de cordon). Son action érosive est nulle et son rôle est essentiellement protectur quand il est posé sur une plage ou un cordon. Par contre, quand il est accroché à une falaise plongeante, il est responsable du creusement d'une encoche et favorise l'effondrement de blocs. Il contribue ainsi au recul de la falaise. Le rôle de transport est dans tous les cas insignifiant. Pendant le dégel les plages sont affectées de microformes glacielles remarqueables (trous, bourrelets, buttes) qui disparaissent chaque été.

En conclusion, les actions glacielles au Spitsberg sont des phénomènes superficiels qui ne sauraient expliquer la formation des strandflats. Par contre, la gélifraction des falaises aidée par une action marine efficace est un processus puissant qui provoque le recul tapide des falaises et le dégagement à leur pied de plateformes dont l'isostasie explique le large développement.

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Sea Ice and Iceberg Action on the Shores and Bottoms of Central and Northwestern Spitsbergen.

The paper gives results of field observations dealing with drift-ice action on shores and shallow bottoms in regards to strandflat development. Even though long-term observations are not available, field investigations, particularly direct observations on fjord floors made by diving, made it possible to evaluate the drift-ice action in an area where azonal agents are predominant. Three types of ice are here considered: icebergs, pack ice, and icefoot.

In the area studied, even though icebergs vary greatly in size, they were always small and came from glaciers advancing into the sea but resting on the bottom. Total height of the glaciers' ice front from which the icebergs are calved is about 100 metres, half being underwater. The submerged part of the icebergs are eroded, perforated by caves, and their base is shaped into downward elongated roots. These sharp tools act upon the bottoms in shallow water, digging grooves on the fjord slopes and depressions over the platforms. These submarine iceberg-made features occur only on clayey fjord floors not exceeding 30 m in depth. Transportation by icebergs is noticeable, but only for glacial sediments which are distributed over the bottom. Iceberg effects are restricted to the fjord area.

Break-up of pack ice occurs suddenly in June. Within a few days ice floes are drifted seaward and melt rapidly when encountering the North Atlantic current. No ice-push ridges have been observed along the shores, and erosional effects of sea ice on sea-bottoms and shores seem very small.

The action of the icefoot is complex, depending upon the type of icefoot, i.e. suspended icefoot or beach icefoot. Generally the major effect of the icefoot is to protect beaches and spits against erosion; however along vertical cliffs it facors the formation of a notch and the fall of rock fragments contribute, in this way, to cliff retreat and the formation of platforms. Transportation of debris by the icefoot is minimum, because the icefoot most commonly melts in situ. Beach microforms (shore ice kettles, mounds, ridges, etc.) which result from the melting of the icefoot, are all destroyed during the summer.

Drift-ice effects in Spitsbergen are surficial and relatively insignificant features in regards to the formation of strandflats, which is mainly related to frost-shattering and marine action.

(Free translation)

Determination of Temperature and Provenance of Ancient Ice Shelves from Ice Rafted Sediments by DAVID J.W. PIPER, Departments of Geology and Oceanography, Dalhousie University, Halifax, Nova Scotia.

The distance from an ice shelf or glacier to the site of the maximum rate of sedimentation by ice rafting is dependent on the temperature of the parent ice. Using this criterion, alternating wet and dry base-ice conditions can be recognized in the Cenozoic of the Ross Sea, Antarctica. Under dry base conditions, production of cold bottom water may also result in winnowing of ice-rafted sediment and the concentration of coarse material.

In Pli-Pleistocene sediments of the Grand Banks of Newfoundland, there are two main sources of ice-rafted detritus. At times of glacial maxima, sediments brought down the Laurentian Channel by the main Laurentides Ice Sheet predominate. During interglacials, crystalline rock fragments from Greenland and Labrador are found.

In central Baffin Bay, most of the ice-rafted material in interglacial times consists of crystalline rock fragments, probably from Greenland. During glacial maxima, large quantities of limestone detritus, presumably from the Canadian Arctic Islands, were deposited. Carbonate deposition may have been enhanced by direct precipitation from seawater beneath cold base-ice shelves.

On Modern Ice Rafting in the Beaufort Sea, Alaska by ERK REIMNITZ and PETER W. BARNES, U.S. Geological Survey, Menlo Park, California.

Gravel, as found in some areas of the Beaufort Sea shelf north of Alaska, often has been ascribed to ice rafting. This gravel could be transported in by pack ice arriving from elsewhere, or it could be introduced into the fast ice locally by various processes active along the coast. In four summer operations involving up to three ships and helicopters, we have seen fine-grained sediment but too little gravel on or in ice to account for the amount of gravel within the Holocene marine sediments on the shelf.

In three field operations during the time of river flooding of the shorefast ice, limited amounts of fine-grained sediment have been found deposited on the ice by rivers, local runoff, wind and slumping. The lower part of the fast ice also contains thin layers of fine sediment picked up by periodic adfreezing to the bottom. However, the pattern and timing of melting and breakup of shorefast ice indicate that conditions are unfavorable for long-range transport of this material.

Concentrations of gravel dropped from ice should develop in areas where water temperatures are relatively high and where drifting ice is retarded by grounding. Topographic highs of the inner and central shelf often are marked by large masses of grounded ice during the summer melt season. However, diving traverses across such shoals indicate that they consist mainly of well-sorted sand, with very few scattered pebbles on the surface.

The general lithology of shelf gravel points to sources in Canada, suggesting long-range transport by ice. Since observations of modern processes indicate that little gravel is rafted today, it may have been transported by ice under different conditions during the past.

Drift-ice Action in Tidal Flats, North Sea by H.E. REINECK, Senckenberg Institut, Wilhelmnhaven, West Germany.

Nearly every year, drift-ice is formed in the tidal flats of the North Sea. The effects of drifting and stranded ice are: 1) erosion caused by the scouring action of water around and behind stranded ice blocks; 2) grooves and tool marks made by drift-ice; 3) deformation structures beneath and beside ice blocks which lie on muddier sediments 4) transport of frozen sediment, e.g. the transport of mud to sandy areas. When the ice melts mud clumps are deposited on sandy flats and sandy beaches; 5) transport of frozen living and dead mollusc shells (*Cardium edule* and *Mytilus edule*) from the intertidal zone into the open sea, i.e. to the shelf.

Sedimentological Consequences of Winter Ice Cover on a Tidal Flat Environment: Great Bay, New Hampshire by DENNIS R. SASSEVILLE, Department of Geological Sciences, University of Maine, Orono, Maine.

During the winter of 1970-71 sedimentological investigations were carried out in a small cove in New Hampshire's Great Bay estuary to study the effects of the seasonal ice cover. Fringing shore ice formed in late December typically contained between 250 and 900 mg/l of particulate matter (PM). The bay ice formed in early January and was characterized by a thin granular upper layer of refrozen snow, a thick middle layer of clean ice (∿ 750 mg/l PM av.), and a bottom layer(s) of frozen mud sometimes rigidly sealed with another clean ice layer but usually very fragile and easily separated from the thick middle layer. Observations made at the edge of the bay ice during flood tide confirmed that much of this fragile mud layer breaks off as flakes and "rains" back onto the surface of the tidal flat.

Considerable resuspension of bottom sediment (> 1,800 mg/l PM) occurred as small waves broke against the outer edge of the ice while it was grounded during low tide. As the bay ice rose with the flood tide, it acted as a buffer to effectively prevent any further major resuspension of bottom sediment. This buffering effect, along with seawater diluation, caused PM concentrations to drop to 3.0 mg/l at high tide. The ebb tide behaved in a reverse manner but with PM concentrations reaching only 15-20 mg/l as the bay ice grounded. However, this resuspended material is likely to be carried out of the cove and redeposited elsewhere in the estuary.

At three locations in the cove, measurements taken before ice formation and after ice breakup indicate that between 0.5 and 3.0 cm of sediment was removed. These measurements are further substantiated by before and after particle size analysis of the surface sediment that demonstrated a net weight loss of 10.5% (5 samples) in the clay (< 8.0 ϕ) fraction.

After the spring breakup of the ice cover, the normally smooth tidal flat surface was characterized by several pronounced geomorphic features: (1) shallow linear scars parallel to ice movement, (2) ice-rafted boulders often with accompanying drag scars, (3) small (< 10 cm high) mud ridges fringing the shore, (4) a heavy concentration of ice-rafted pebbles and boulders deposited at the mouth of the cove above the low tide limit, (5) small circular pits (1-2 cm diam.) of undetermined origin covering the surface of the tidal flat, (6) destruction of the previous winter's ice-rafted mud clumps by overriding by and incorporation into the pack ice, and (7) the presence of newly ice-rafted mud clumps stranded in the cove.

Within two months of spring breakup no observable effects of the ice cover remained except for the new mud clumps. Thus, the major consequences of the winter ice cover on the study area was to remove sediment and aid in the destruction of any existing primary sedimentary structures.

Modes of Ice Deposition on Alaskan Arctic Beaches by A.D. SHORT, Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana.

Observations along the northern Alaskan coast during 1972 indicate that deposition of ice on arctic beaches is dependent upon (1) a supply of ice, either from pack ice or newly formed frazil or sludge ice; (2) wind- and tide-generated currents to move ice into the nearshore zone; and (3) wave action to carry ice onto the beach. Three basic types of ice are deposited on arctic beaches: drift ice, either pack or sludge ice, and frozen swash mass.

Pieces of winter or pack ice may be deposited on beaches at any time during the summer season. Following breakup it returns to the shore under the driving force of westerly winds and onshore Ekman drift. On entering the nearshore zone the ice is sorted, the largest pieces grounding offshore and the smallest being deposited at the swash limit.

Sludge ice first forms on brackish lagoonal and estuarine water bodies during periods with temperatures below 0°C. Once it is formed, wind- and tide-generated currents regularly flush the sludge into the nearshore zone, where waves may wash it onto the beach.

When air and water temperatures are below 0°C, swash mass, foam, and spray begin to freeze on the beach face. In addition, frozen swash mass and sediment may be deposited over snow-covered beach surfaces.

The above processes result in the formation of beach structures composed of embedded pieces of ice, sludge ice berms, and layers of frozen swash mass, foam, spray, and snow, all interlain with layers of sediment. Melt of the ice and snow generates beach subsidence and collapse features such as kettle holes, pitting, distorted bedding, and sand and gravel cones and ridges.

Sea and Nearshore Ice Effects on Coastal Processes in the Canadian Arctic Archipelago by R.B. TAYLOR, Geological Survey of Canada, Ottawa, Ontario and S.B. McCANN, Department of Geography, McMaster University, Hamilton, Ontario.

The presence of sea ice and nearshore ice for long periods of each year is an important factor in causing the low energy beach environments of the Canadian Arctic Islands. However, although the effects of ice are predominantly to limit wave generation and wave action, a positive contribution is also achieved by ice push and ice melt features. The role of ice in an arctic beach environment has been documented as part of a long term study, 1968-71, of coastal processes at Radstork Bay, southwestern Devon Island, and it is evident that sea-ice conditions can vary greatly from year to year resulting in great differences in beach plan and profile.

Field investigations in 1972 were expanded to include four new beach environments (Table 1), each chosen to represent different ice conditions in terms of length of open water season, ice characteristics, particularly in the nearshore, and the extent of ice-formed features on the beach. The dependence of coastal processes and resultant beach change on sea-ice conditions was also examined. An attempt was made to establish the average length of open-water season at each of the study areas in terms of when the beach is subject to actual wave action. The work was based on the sea-ice reconnaissance records for the Atmospheric Environmental Service, Ottawa, Canada, from 1964 to 1972 and on any available aerial photographs.

The basic field observations at each of the study areas and the more general research on the open-water season are regarded as essential before complex marine facilities can be constructed or safely maintained.

Table 1 - Location and Nearshore Ice Characteristics of Study Sites Canadian Arctic Archipelago 1972.

Location	Latitude and Longitude	Average Length of Open Water Season	Coastal Characteristics	Nearshore ice Characteristics
1. Radstock Bay (southwest Devon Island)	74°43'N 91°10'W	44 days (d)	Bay situation on open coast with moderately long fetches	Well developed icefoot, some buried ice and small push features on beach
2. North shore (Somerset Island)	74°12'N 93°15'W	67 d	Open coast, moderately long fetches, raised beaches dominate coastline	Well developed icefoot, large ice melt features and numerous ice-push mounds
3. Hooker Bay (West Bathurst Island)	75°43'N 100°30'W	25 d	Bay situation in low highly indented coastline	Absence of icefoot ridge of ice at LTM some anchor ice in nearshore
4. Pond Inlet (North Baffin Island)	72°45'N 77°35'W	60 d	Semi enclosed fiord coast	Ice attached to rock coast, some ground ice in beach bluffs
5. Makinson Inlet (southeast Ellesmere Island)	77°15'N 81°30'W	32 d	Enclosed fiord coast with tidewater glaciers	Well developed icefoot, absence of ice-push features, some buried ice ridges at LTM