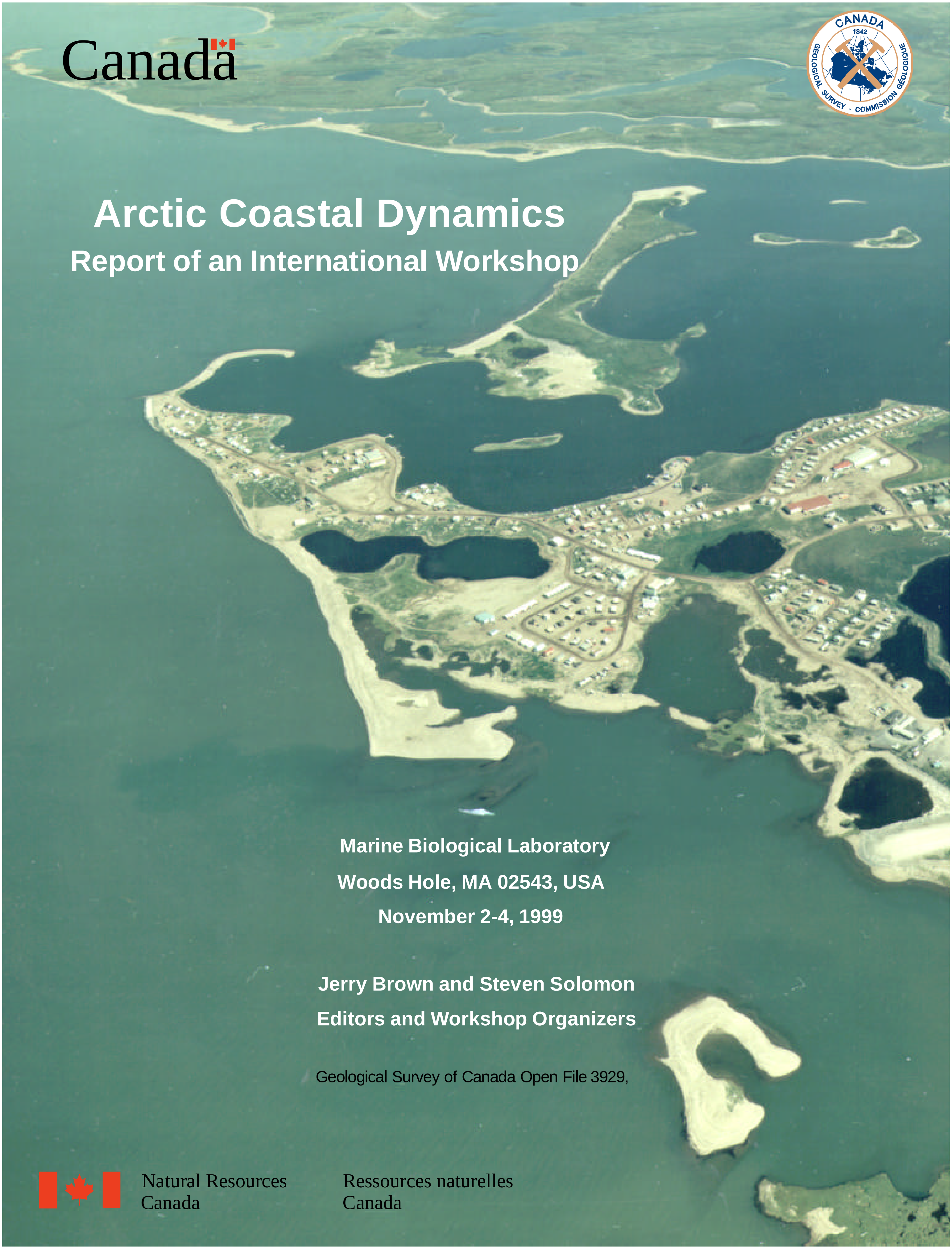

Canada

Arctic Coastal Dynamics

Report of an International Workshop

Marine Biological Laboratory
Woods Hole, MA 02543, USA
November 2-4, 1999

Jerry Brown and Steven Solomon
Editors and Workshop Organizers

Geological Survey of Canada Open File 3929,

Natural Resources Canada
Ressources naturelles Canada

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Attendees of the Arctic Coastal Dynamics Meeting

ACKNOWLEDGEMENTS

The workshop was supported by NSF Grant No. OPP-9818294 to the American Geophysical Union, and NSF Grant No. OPP-9818120 to the University of Alaska. Both grants are part of the Office of Polar Program's program the Russian-American Initiative on Shelf-Land Environments (RAISE). A number of participants provided their own travel and local support, and their sponsor's contributions are greatly appreciated. The staffs of the Marine Biological Laboratory and its Swope Conference Center provided excellent logistical support. Similarly the National Academy of Sciences J. Erik Jonsson Woods Hole Center provided an excellent venue for the final day's sessions. Sue Donovan of the MBL Ecosystems Center provided invaluable assistance with computer interfaces and graphics and assisted in the preparation of the final poster presentation. Volker Rachold and Steve Solomon prepared the initial version of the workshop poster. Finally, the contributions of the participants, both at the meeting and throughout the review process are greatly appreciated.

Cover - The cover photograph is an oblique aerial view of the community of Tuktoyaktuk, Northwest Territories, Canada.

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1.0. SUMMARY

The circum-Arctic coastal margin is about 200,000 km long and is the interface through which land-shelf exchanges are mediated. Sediment input to the Arctic shelf resulting from erosion of ice-rich, permafrost-dominated coastlines may be equal to or greater than input from river discharge. In addition, climate change in the Arctic is predicted to be more rapid and more intense than at lower latitudes. Determining sediment sources and transport rates along high latitude coasts and inner shelves is critical for interpreting the geological history of the shelves and for predictions of future behavior of these coasts in response to climatic and sea level changes. In order to address these and methodological issues, a workshop was held in Woods Hole, Massachusetts, November 2-4, 1999, and attended by 45 participants from Canada, Germany, Russia and the United States. The workshop's primary sponsor was the NSF's Office of Polar Program and its program “Russian-American Initiative on Shelf-Land Environments” (RAISE).

Objectives: Workshop objectives were developed in a series of pre-workshop planning meetings:

Develop and apply a classification system for coastal mapping and for assessing the sensitivity and erosion potential of Arctic coasts.

Identify, describe and recommend techniques applicable for use in mapping and measuring erosion and accretion.

Identify critical processes that affect dynamics of high latitude shorelines.

Develop estimates of erosion rates for representative circum-Arctic coastlines.

Accomplishments: Following the first day of invited presentations and posters, workshop participants divided into small breakout groups. Results and conclusions of these deliberations were:

Classification and Mapping: Development of a consistent and generalized classification for high-latitude coasts is essential for development of circum-Arctic databases and maps. An acceptable classification must be broad enough to encompass existing schemes while capturing fundamental information for assessment of climate change impacts and coastal processes. A physical classification scheme was developed based on morphology and materials. Specific regions were identified for prototype mapping assessment.

Coastal Processes: In high latitudes, both ground ice in permafrost and sea ice have dramatic influences on coastal change and sediment transport. The primary forcing parameters for coastal change in the circum-Arctic regions and methods for compilation of environmental parameters were enumerated.

Ground-ice Estimates and Mapping: Massive bodies of ground ice occupy large volumes of onshore permafrost and facilitate rapid transgression of coasts. Consensus was reached on direct and indirect methodologies for estimating ground ice volumes and presentations of data on maps.

Monitoring and Site Requirements: Spatial and temporal changes in beach and nearshore morphology and rates of erosion are critical to our understanding of processes and trends. A suite of standard tools and techniques were agreed upon for development of long-term coastal monitoring sites and their measurement. This requires metadata information for the selection and the establishment of key monitoring sites and direct involvement of local communities.

Recommendations: Workshop participants approved the following:

1.High-latitude coastlines, dominated by cryological processes, are sensitive to climate variations and changes, and therefore, the associated coastal impacts and adaptations should be appropriately recognized in the forthcoming Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and by national and international organizations.

A concerted and coordinated international data synthesis and mapping effort is required to properly assess the magnitude of sediment derived and transported from the coast onto the shelf.

An international network of representative key and observational sites is required for assessing long-term changes, including threats to local communities, habitat modifications, and carbon and sediment budgets.

A local community-based monitoring protocol should be part of an international design with observations conducted by Arctic residents.

There is a need to prepare a synthesis of existing data and information concerning fluvial sediment inputs to the Arctic shelves and basins.

Future Activities: International planning, cooperation and funding of national, bilateral and multi-national projects are required to accomplish the following:

Develop a circum-Arctic monitoring network of key and observational sites based on a metadata inventory of potential regional sites.

Construct databases for web-based delivery.

Apply the coastal classification to representative sites.

Develop circum-Arctic map products of coastal sediment yields, climate change sensitivity, severity of environmental forcing, etc. Participate in the development of a new referenced Arctic shoreline.

Explore and develop international cooperation and projects with other organizations including the International Arctic Science Committee (IASC), Intergovernmental Oceanographic Commission (IOC), International Hydrographic Bureau (IHB), IGBP-Land-Ocean Interaction in the Coastal Zone (LOICZ), Arctic Paleo-Discharge (APARD), and IGU commissions.

Convene workshops periodically to assess progress and facilitate the development of specific activities.

Information available: Posters highlighting the workshop's accomplishments were presented at the Laptev Sea conference in St. Petersburg, Russia (November 26-28,1999),at the AGU Fall Meeting in San Francisco (December 13-17,1999), and at other meetings in 2000 to inform individuals and organizations of the present status and future directions of the Arctic Coastal Dynamics (ACD) initiative. The poster and report are available on ftp://agc.bio.ns.ca/pub/solomon/AGUReport. For additional information contact the workshop convenors: Jerry Brown (jerrybrown@igc.org) or Steve Solomon (ssolomon@agc.bio.ns.ca), on behalf of the International Permafrost Association (IPA) and its Coastal Erosion Subgroup.

2.0. INTRODUCTION

2.1. BACKGROUND

Arctic continental shelves comprise 30% of the area of the Arctic Ocean and contribute about 20% of the world's continental shelf area. This extensive circum-Arctic coastal margin is the interface through which land-shelf exchanges are mediated. Though generally only a few kilometers wide (except in the vicinity of large deltas), the coastal zone of the Arctic Ocean is the site of dramatic changes in not only the land and ocean but also in the cryosphere and biosphere. The Arctic coastlines are highly variable, can be stable or extremely dynamic and are the site of most of the human activity that occurs at high latitudes. Extraction of natural resources occurs in many locations around the Arctic Ocean creating the need for port facilities and the potential for pollution. These pressures are only likely to increase with time.

Models predict that global increases in carbon dioxide will cause warming in the high latitudes and changes in timing and amounts of precipitation. Secondary effects include changes in timing of freeze-up and break-up of ice, ice volumes and movement, sea level and discharge from large rivers, and breakdown of hydrates releasing greenhouse gases. The combined impacts of these primary and secondary effects on sediment (along with carbon and associated dissolved and particulate materials) delivery to the coast could be very large. There will likely be an impact on global carbon budgets since continental margins are the most important locations in the ocean for sequestering organic carbon (e.g. Berner, 1982; Romankevich, 1994; Smith and Hollibaugh, 1993) and the "burndown" of carbon in marine sediments influences the global cycling of many other elements (e.g. Christensen, 1994).

The importance of many of these issues (among others) was also identified during a joint workshop on Arctic coastal processes held by the U. S. Geological Survey and Geological Survey of Canada in 1990

(Taylor and Barnes, 1990). That workshop called for an international meeting on Arctic coastal processes and publication of summary papers on our state of knowledge.

2.2. NEED FOR INTERNATIONAL SYNTHESIS

While local and regional scale investigations have provided some insight into high-latitude sediment budgets, no attempts have been made to synthesize and expand them to encompass the circum-Arctic region. As an initial step, establishment of international standards for mapping and measuring high-latitude coasts and their dynamics is required in order to investigate the role of shoreline processes (erosion, transport) in the circum-Arctic sediment budget.

Data on sediment inputs from coastal erosion exist from portions of the Beaufort Sea and parts of the Laptev Sea among other locations. These data provide tantalizing information about the relative importance of rivers and coasts, but also illustrate potential difficulties in comparing data from disparate sources. Along a portion of the Canadian Beaufort Sea (CBS) coast (1150 km long), sediment delivery from coastal erosion is about 5.6 Mt a^{-1} (Hill et al, 1991). Sediment delivery from the Alaskan Beaufort Sea coast (344 km) is 4.8 Mt a^{-1} (Reimnitz et al 1988). The amount of sediment released to the sea from a portion of the Russian Laptev Sea coast (5200 km) is 58.4 Mt a^{-1} (Rachold, Grigoryev, Are, Solomon, Reimnitz, Kassens, and Antonow, submitted to *Geologische Rundschau*) (Table 2.1). Note that the estimated sediment delivery from coastal erosion along the CBS is about 0.005 Mt km^{-1}. This is about half of that for the Laptev Sea coast (0.011 Mt km^{-1}) and about one third of that for the Alaskan Beaufort coast (0.014 Mt km^{-1}. Both the Laptev Sea and CBS coast summaries only include subaerial erosion while the Alaskan estimate also includes erosion of the subaqueous profile.

Sediment input from rivers draining into the Arctic Ocean is also highly variable and subject to considerable uncertainties. As an example, the Mackenzie River discharges about 127 Mt a^{-1} to its delta, of which approximately half is trapped in the delta (MacDonald et al. 1997). The Lena River discharges from 12 to 21 Mt a^{-1} of sediment, of which only 2.1 to 3.5 Mt may reach the sea (Are, 1998). Thus, input from coastal erosion rivals or exceeds river inputs in some areas (Are, 1998, 1999; Reimnitz et al 1988).

Figure 2.1 illustrates the general geometry employed by Reimnitz et al. (1988) to estimate the sediments introduced into the sea by coastal erosion. These calculations require estimates of excess ice volumes (see section 5.4). Are (1999) subsequently refined these estimates as a function of different erosion regimes.

Estimation and understanding of coastal sediment input and evolution requires compilation of information about environmental forcing and local geological and cryological conditions. Mean annual ground temperatures vary from less than -10°C on land to above zero in the nearshore coastal waters over a matter of several 10s of meters. Subaerial and subsea permafrost degrades rapidly within 10's of meters of the shoreline and large blocks of frozen ground and saturated, thawed sediments fall into the shallow seas and lagoons at rates as high as 20 m or more every year (e.g. Are, 1988; Dallimore et al 1996; Dyke and Wolfe, 1993; Grigoryev, 1996; Harper, 1990; Reimnitz et al 1988; Solomon et al. 1993). Ice content within frozen sediments along with the presence of winter ice and associated ice scouring and bulldozing are the primary differences between temperate and high-latitude coastal processes. Rates of coastal erosion and evolution in many parts of the Arctic are rapid by any standard, especially when only the ice-free period during which wave activity is possible is considered.

In some locations, ice entrainment processes are thought to be of equal or greater magnitude in fostering sediment removal and coastal erosion (Reimnitz et al. 1988). Subaerially, interstitial and/or massive ice in sediments influences the high latitude erosion process by providing transient strength to unlithified sediments allowing the development of over-steepened cliffs and under-cut notches (Are, 1988; Dallimore et al. 1996). Thermal subsidence of transgressed coastlines may help to drive erosion in some locations (e.g. Are, 1988; Shah, 1978; Wolfe et al. 1998). Entrainment of sediment in frazil ice and its subsequent transport is known to be very important in a variety of Arctic settings (e.g. Reimnitz and Barnes, 1987). It will be necessary to capture the full range of high-latitude coastal variability in order to build comprehensive databases of sediment delivery.

Furthermore, measurements of these differences in rates and processes will require standard approaches of observations if we are to develop an accurate and consistent assessment of sediment input to the circum-Arctic shelves and basin.

Table 2.1. Comparison of riverine and coastal sediment input into the Laptev and Beaufort Seas.

	Laptev Sea	**Canadian Beaufort Sea**
riverine sediment discharge (Mt a^{-1})	24.10(1)	64.45(2)
total coastal erosion sediment input (Mt a^{-1})	58.4(4)	5.6(3)
coastal erosion sediment input (Mt a^{-1}•km)	0.011(4)	0.005(3)
riverine/coastal proportion	0.4	11.5
(1)Gordeev et al. 1988; (2)Macdonald et al. 1997; (3)Hill et al., 1991; (4)Rachold, Grigoryev, Are, Solomon, Reimnitz, Kassens, and Antonow (submitted to *Geologische Rundschau*)		

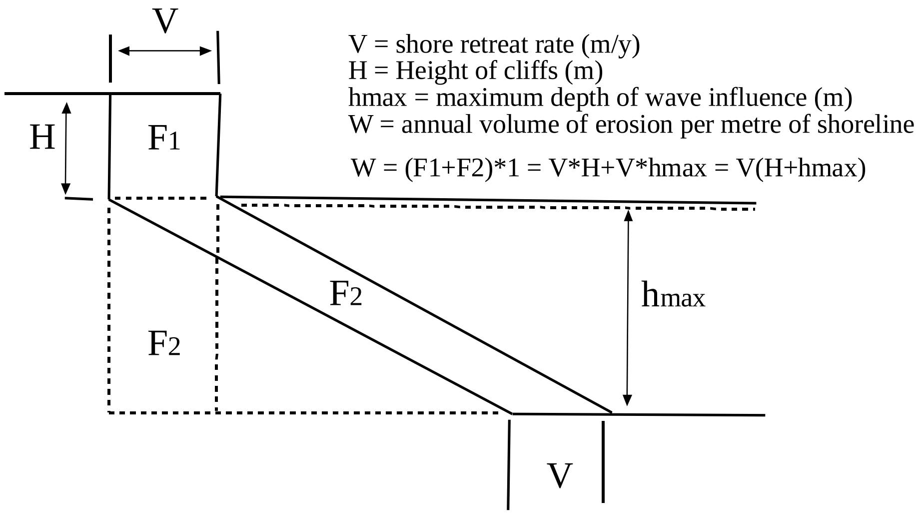

Figure 2.1. General geometry used for calculation of sediment yield (after Are, 1999).

3.0. OBJECTIVES AND ORGANIZATION

3.1. OBJECTIVES

In order to develop the basis for answering many of these questions, the following objectives were established in a proposal to the U.S. National Science Foundation:

Develop and apply a classification system for coastal mapping and for assessing the sensitivity and erosion potential of Arctic coasts.

Identify, describe and recommend techniques applicable for use in mapping and measuring erosion and accretion.

Identify critical processes that affect dynamics of high latitude shorelines.

Develop estimates of erosion rates for representative circum-Arctic coastlines.

3.2. PLANNING

The provisional agenda for the workshop was developed at a small planning meeting in Potsdam, Germany in June 1999, and attended by Solomon and Russian and German participants in the Laptev Sea program. The discussions resulted in requests for invited presentations and poster abstracts. Brown met with the Solomon and other Geological Survey of Canada participants in Bedford, Nova Scotia in September to go over final agenda and plans for the breakout groups. A loose leaf booklet containing the agenda, abstracts, breakout assignments, participants, and other information were compiled and available at the workshop (see appendices).

The workshop's primary sponsor was the NSF's Office of Polar Program and its program "Russian-American Initiative on Shelf-Land Environments (RAISE)". A grant was awarded to the American Geophysical Union to conduct the workshop and provide partial travel and local support. In order to insure a well-balanced venue and participation, a small International Organizing Committee was formed and consists of: Felix Are (Russia), Jerry Brown, (USA and workshop convenor), Volker Rachold (Germany), and Steve Solomon (Canada, co-convenor). Jerry Brown and Bruce Peterson (MBL) served as the local organizers. The workshop was organized under the auspices of the International Permafrost Association, its Coastal Subgroup chaired by Steve Solomon, and its Working Group on Coastal and Offshore Permafrost, co-chaired by Hans Hubberten (Germany) and Nikolai Romanovskii (Russia). Among the approximate 45 participants were a number of graduate students and agency representatives from both the U.S. and Canada, several Alaskan natives including three high school students from Barrow and Point Hope. The International RAISE Steering Committee met following the workshop and several of its members participated in the workshop (Appendix E).

3.3. IMPLEMENTATION

The first day of the workshop was devoted to invited presentations, plenary discussions and posters. The remaining time was spent in breakout groups and plenary sessions to review progress and overlaps . The following tasks were assigned to breakout groups.

Classification and Mapping: Review coastline classifications and agree upon the most appropriate one for purposes of mapping and estimating erosion, sediment yield and deposition. Develop a list of annotated attributes for GIS-based, circum-Arctic mapping at 1:1,000,000. Recommend mapping approaches to assess long-term impacts including those related to sea level changes, loss of habitats and archeological sites, and onshore-offshore construction.

Coastal Change Methodology: Review methods for measuring changes in coastline including ground surveys (transects, point measurements), comparisons of aerial, video, satellite and ground photographs, navigational and other maps and historical records. Recommend standard procedures for establishing long-term monitoring sites including ground, airborne, and space observations (e.g. GPS, lidar, radar, video, etc).

Coastal Processes: Review dominant water- and ice-related erosional, transport and depositional processes, methods of measuring shoreface parameters, and calculating profiles and coastal changes for major types of coasts. Recommend field and computational methods. Recommend and/or select corridors or locations for permanent monitoring sites.

Ground-ice Estimates: Review methods for estimating ground-ice content (boreholes and shotholes, geophysical, photographic/video interpretation, thermokarst, thaw lake depths, etc). Develop range of estimates for mapping at different scales and landscapes and recommend method for calculating ice volumes. Revise or validate estimates of ground ice for selective sites along circum-Arctic coast based on existing 1:1,000,000 to 1:10,000,000 maps.

Cultural and Economic Implications (Community-based Monitoring): Describe implications and impacts resulting from erosion, sedimentation and inundation; both present and in the future, including loss of private and public lands, habitats, and archeological and cultural resources. Provide examples of methods for mitigation and current practices including offshore developments and coastal protection.

Common task for all groups:

Environmental Data: Review and compile lists of available and future ground- based and satellite data and products required for coastal monitoring including bathymetric surveys, altimetry, land and sea climates, sea ice, tides, etc. Annotate computer generated strip maps with available site information and erosion and accretion estimates. Participants were requested to bring data (digital or paper products) that can be incorporated into a circum-Arctic coastal database.

These data and information types include: measured erosion rates, profiles (shoreface, beach and cliffs), maps showing ice content, coastal materials, coastal morphology, environmental data on the distribution of sea ice, winds, waves, currents and storms along high latitude coasts, and information on distance to 2 m, 5 m and 10 m contours, and open and gray literature citations (with geographic coordinates).

Digital profile data should include (1) distance from shore, water depth or elevation; or (2) geographic coordinates, water depth or elevation. Information for vertical datum (e.g., mean sea level, chart datum, water level at time of data collection) should be included, along with a map of the location and coordinates of the start point and bearing of the profile line. If geographic coordinates are supplied, the projection and datum should be provided.

4.0. SUMMARY OF INVITED PAPERS AND POSTERS

Eight invited reports and some 30 poster were presented (see abstracts; Appendix C). The invited reports dealt with of field techniques for measuring, monitoring, and mapping of high latitude coastal changes (Forbes, Grigoriev and Rachold), and determining their morphology (Are). Other reviews included ground-based and remotely sensed techniques (Eicken), and the requirement for a common classification of coasts (Solomon). The importance of ice in transporting sediments was demonstrated in a video previously prepared by Reimnitz. Results of pan-Arctic river runoff based on observational discharge records into the Arctic seas (Figure 4.1) was presented by Lammers. The results of a recent workshop on assessing bathymetry changes and fresh water inputs on shelf and ocean circulation for the past 20,000 years were summarized by Forman.

A number of posters presented results from past and current studies of coastal changes from Russia, Canada and Alaskan coast. Other posters illustrated the role of ground ice, sea ice, and storms on erosion and aggradation of Arctic coasts. Table 4.1 summarizes organizational interests, past, present and future, and regions of interest for workshop participants based on subdivisions presented in Figure 4.1.

Table 4.1. Provisional interests and responsibilities for monitoring sites in the Pan-Arctic seas (includes synthesis of past data and new field observations).

COUNTRY/SEA	ORGANIZATIONS	WORKSHOP PARTICIPANTS
Alaska/U.S.A.		
Bering Sea	National Park Service, MMS	Cooper, Jordan, Jorgenson, Mason, Naidu
Chukchi Sea	NSF, USGS, NOAA, MMS	Anderson, Brigham-Grette, Cannon, Edsale, Hank, Klene, Lane, Litchard, Mason, Smith, Tingook
Beaufort Sea	FWS, NSF, USGS, NOAA, MMS	Brown, Jorgenson, Lawson*, Morkill, Naidu, Peterson, Reimnitz, Romanovsky, Shur, Vandegraft, Walker
Canada		
Beaufort Sea	Geological Survey of Canada McGill University	Couture, Dyke, Pollard, Solomon, Strommer
Arctic Archipellago	Geological Survey of Canada McGill University	Couture, Forbes, Pollard, Taylor
Hudson Bay	Laval University	Allard
Foxe Basin & Hudson Strait	Geological Survey of Canada	Forbes, Taylor
Baffin Bay	Geological Survey of Canada	Forbes, Taylor
South Greenland Sea	Geological Survey of Canada	Forbes, Taylor
Denmark		
Greenland Seas, Baffin Bay	*Insititute of Geography	*Nielsen, Rasch
Norway/Sweden		
Norwegian Sea	*	*
Barents Sea	*	*
Russia		
Barents Sea	VNIIOkeangeologia	Cherkashov, Forman
Kara Sea	VNIIOkeangeologia Earth Cryopshere Institute	Cherkashov, Forman, Leibman, Vasiliev
Laptev Sea	Permafrost Institute Alfred Wegener Institute Pacific Oceanological Inst. (POI)	Are, Eicken, Grigoriev, Hubberten, Reimnitz, Romanovskii, Semiletov , Rachold
Eastern Siberian Sea	Permafrost Institute	Grigoriev, Ostroumov, Pitulko
Chukchi Sea	Permafrost Institute	Kotov*
Bering Sea	Permafrost Institute, POI	Kotov*, Semiletov
Circum-Arctic	NSF, NASA, USGS, INTAS-MSU	Anderson, Christensen, Johnson, Lammers, Melnikov, Mitchell, Peterson, Proshutinsky, Streletskaya, Williams

*not present; names to be added.

Additional participants identified at subsequent meeting in Pushchino May 2000

Barents Sea, Arctic and Antarctic Research Institute, *Bolshiyanov
Kara Sea, Moscow State University, *Ogorodov, *Pokrovsky
Laptev Sea, Arctic and Antarctic Research Institute, *Medkova
Eastern Siberian Sea, Pacific Oceanological Institute (POI), *Zimov
Circum-Arctic, Shirshov Institute of Oceanology, *Gordeev

Figure 4.1. Subdivision of Arctic organized by sea and drainage basin boundaries (courtesy of the Global Hydrological Archive and Analysis System, University of New Hampshire). Please see http://www.r-arcticnet.sr.unh.edu/main.html for updated figure.

5.0. RESULTS OF BREAKOUT GROUPS

5.1. CLASSIFICATION AND MAPPING

Participants: Steve Solomon (rapporteur), Don Forbes, Jim Jordan, Torre Jorgenson, , Douglas Vandegraft, Julie Brigham-Grette (day one), Nikolai Romanovski (day one)

Agreement on a consistent and generalized classification for high-latitude coasts is essential for development of circum-Arctic databases and maps. An acceptable classification must be broad enough to encompass existing schemes while capturing fundamental information for assessment of climate change impacts and coastal processes.

5.1.1. Classification

Several classification systems were discussed and spirited discussions lead to the agreement that it was necessary to develop a new and objective classification by first compiling maps of generalized physical attributes of the coast (i.e. morphology and materials). These maps will be compiled into a spatial database which can be stored and manipulated in a geographical information system in conjunction with other databases (e.g. ice content database, circum-Arctic permafrost map). Classification of the coast is then based on the identification of segments of coastline which exhibit homogeneous forms and material types. For an excellent explanation of this mapping methodology, the reader is referred to the British Columbia website on physical shore-zone mapping at the following address:

http://www.for.gov.bc.ca/ric/Pubs/Coastal/Pysshore/index.htm#phy.4.0 .

In general, this shore-zone mapping method involves the division of the coast into along-shore units with a set of cross-shore zones. Some discussion was devoted to the appropriate scale for mapping and it was agreed that mapping for a circum-Arctic compilation is most appropriately performed at a scale of 1:250,000 with compilation at the 1:1,000,000 scale. The proposed zonal or cross-shore classification as agreed upon by the breakout group is shown in Table 5.1 and schematically illustrated in Figure 5.1. In this mapping scheme each along-shore unit is divided into four cross-shore units which are described in terms of their shape (or morphology) and their material type. The cross-shore units are identified as onshore, backshore, frontshore and offshore. These designations are defined in Table 5.1 and are specific to this classification. The term “frontshore” was defined to include both the foreshore and the surf zone whereas the term “backshore” was defined to refer primarily to the area landward of the active beach. The “onshore” category refers to the local to regional setting of the zone that is adjacent to those zones which are immediately affected by marine processes.

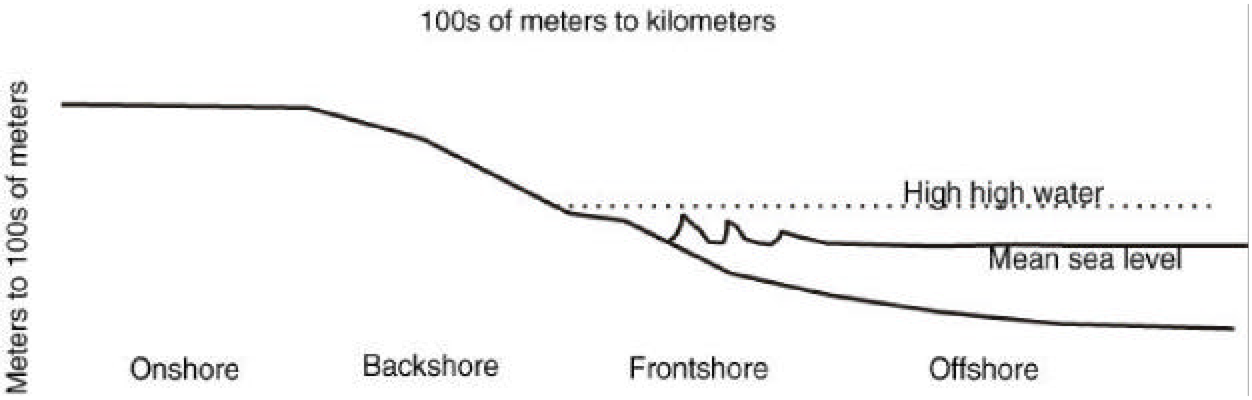

Figure 5.1. Schematic representation of cross-shore zones for classification.

The onshore form category describes the elevation while relief describes the steepness. The presence or absence of lakes and thaw lakes is also noted. The backshore and frontshore forms attempt to describe the shape of those zones in genetically neutral, geometrically defined terms. We also discussed the possibility of including a quantitative description of shoreline complexity in this category along the lines of a fractal dimension. Although it was agreed that this would be a useful index, no consensus on the methodology was achieved. The offshore zone, like the onshore zone provides context for the classification of the coastal region and is described in terms of its steepness and relief characteristics (i.e. slope or distance to a bathymetric contour).

The same set of form categories apply to both backshore and frontshore zones. Examples of possible morphologies which could be described using this system include the following (Figure 5.2):

- The generic *ridge and basin* form is designed to capture a range of genetic morphologies explicitly including barrier-lagoon systems.
- *Ridged or terraced* frontshore deposits include beach ridge plains whereas sand or gravel *slope* deposits in the frontshore refer to beaches. Frontshore *flats* include sandy or muddy intertidal flats as well as bedrock platforms.
- Backshore *ridge and basin* morphology would include relict lagoon systems behind an aggrading frontshore *ridged* sand or gravel (i.e. beach ridge plain), whereas a *ridged* and sandy backshore would refer to dunes.
- In bedrock dominated areas, fjord *cliffs* may extend through all four cross-shore zones with no other modifiers; alternatively *slopes* or *flats* could be present in the frontshore or backshore.

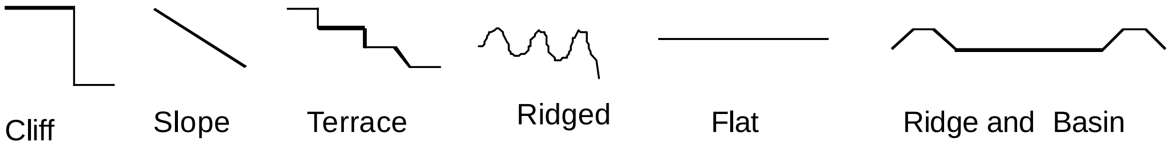

Figure 5.2. Relief forms or morphologies used in the classification.

For all cross-shore zones the material should be specified as shown in Table 5.1. Materials include unlithified and lithified components as well as ice (ground ice, sea ice or glacier ice). Data sources should be specified as part of the database development along with comments including local or genetic shore-type class if available. Approaches to the incorporation of data on environmental forcing was also discussed. The types of data included climate (wind, pressure, temperature, etc), oceanographic (tides, surges, waves, etc.), ice conditions (timing of break-up, freeze-up), and hydrological data (river discharge).

5.1.2. Mapping

The final half day of the workshop was devoted to mapping trials using the available expertise at a variety of locations in Russia, Canada and the U.S. The consensus from the participants was that it was possible to apply the mapping classification at most sites with little trouble, although a more thorough set of definitions is required along with the development of a coding scheme for mapping.

An evaluation of the classification system is planned for the year 2000 with volunteers to map in a range of locations:

Barrow – Brown, Mason
Arctic National Wildlife Refuge – Morkill
Eastern Canadian Arctic example – Taylor/Forbes
Chukchi example –Jordan/Mason
Laptev Sea – Grigoriev/ Rachold
Yamal Peninsula – Vasiliev/ Shur
E. Siberia/Chukotka – Ostroumov/ Grigoriev/ Kotov
Colville River Delta – Jorgensen/Walker
Canadian Beaufort Sea – Solomon

Table 5.1. Proposed classification and definitions.

Onshore	**Backshore**	**Frontshore**	**Offshore**
Zone immediately landward of the backshore zone to 1 km from extreme high water	from the high water large tide line land-ward to the local cliff tops or the landward extent of marine processes	from the high water large tide line to the outer boundary of the surf zone	seaward of surface
FORM - code	FORM - code	FORM - code	FORM - code
Delta - D	Cliff (50^{o}) - C	Cliff (50^{o}) - C	Steep -S
Lowland (<10m) - L	Slope (3-50^{o}) - S	Slope (3-50^{o}) - S	Gentle - G
Upland (10-500m) - U	Flat (<3^{o}) - F	Flat (<3^{o}) - F	(based on 2/10 m
Highland (>500m) - H	Ridged (terraced) -R	Ridged (terraced) -R	isobaths capture
	Ridge and basin - RB	Ridge and basin - RB	shape)
	Anthropogenic -A	Anthropogenic -A	
RELIEF (distance to)	Shorezone complexity ###		RELIEF (distance to)
10 m contour (###)			2 m isobath (###)
100 m contour (###)			10 m isobath (###)
500 m contour (###)			20 m isobath (###)
Lakes (presence/ absence/thaw)			100 m isobath (###)

MATERIAL for four cross-shore zones are classified as follows:

Unlithified - code	**Lithified** -code	**Ice** - code
mud-dominated - m	sedimentary	floating - f
sand-dominated - s	igneous/metamorphic	grounded - gr
gravel-dominated - g	poorly lithified	
diamict - d organic - o		**Man-made structures**
Mixtures- e.g. ms,sg		
Ground ice: wedges and massive		

Table notes: Mapping methodology to use coding convention:

Onshore_form/ backshore_form/frontshore_form/offshore_form.
Onshore_material/backshore_material/frontshore_material/offshore_material

Relief distance may be undefined if there is no elevation contour found which is orthogonal to the coast (e.g. island or peninsula).

5.2. Coastal Change Methodology and Site Requirements

Participants: Volker Rachold (rapporteur), Caroline Cannon, George Cherkashov, Mikhail Grigoryev, Mae Hank, Anne Klene, Ben Lane, Loren Litchard, Owen Mason, Anne Morkill, Jackie Smith , Bob Taylor, Ron Tingook.

Various methods based on ground surveys, comparison of aerial photographs, and historical information may be used to quantify coastal changes. The objectives of this working group were to summarize and review these methods and to recommend standard procedures for establishing long-term monitoring sites (key sites) and observational sites. These methods are based on standard protocols commonly used to study shoreline erosion and accretion, including use of evolving technologies that may further improve surveying capabilities. The circum-Arctic coastal change monitoring program would integrate information from periodic field surveys of offshore and onshore profiles, remotely-sensed observations, and secondary data sources. The following criteria and available methods were identified.

5.2.1. Field Surveys

5.2.1.1. Offshore profiles would be measured from the waterline at high tide up to at least the 10 m water depth, where possible. A minimum of three offshore profiles would be measured at each field monitoring site. In coastal areas where barrier islands or bars are present, the offshore profile would include both the shoreward lagoon (frontshore) and seaward offshore waters. Field methods for measuring offshore profiles include bathymetry surveys (shoreface profiles), echo sounding (single and multibeam), subbottom profiling (shallow seismic), and sidescan sonar profiling.

Ancillary data on other physical attributes in the offshore zone could also be collected for a broader understanding of the coastal processes at each monitoring site. Conductivity, transparency and depth (standard CTD), and current velocity should be recorded. The thickness of the active layer would be measured by probing, coring, or other surface sampling.

The sampling interval for offshore profile surveys would depend primarily on site-specific objectives and methods, and range from annual field visits (bathymetry, sidescan, CTD etc.) to a single site measurement.

5.2.1.2. Onshore features would be measured in conjunction with the offshore sections to provide a seamless profile from at least the 10 m water depth landward to the flood limit. The position and configuration of onshore features would be measured in relation to benchmarks using standard surveying methods, including differential GPS, optical (visual) survey, photo points, and videography. Measurements should occur at frequent intervals to create a continuous profile, if possible; otherwise, the location of the cliff edge, cliff base, and waterline should be the minimum set of measurements.

Ancillary data for onshore profiles would include thickness of the active layer, core sampling to determine vertical stratigraphy (see Section 5.4 on ground ice), documenting the height and landward extent of storm surges by measuring driftwood lines, and interpreting site Quaternary history.

The onshore profile survey’s sampling interval would depend primarily on the dominant composition of the coastal features, ranging from annual field visits in ice complex areas where change is expected to occur frequently, to 5-year intervals in areas of coarse material where coastal features are expected to remain relatively stable.

5.2.2. Remote Sensing

Various formats are available for the remote sensing of coastal changes, including conventional aerial photography, high-resolution satellite images, airborne laser altimetry, and synthetic aperature radar. Change detection analyses should be performed by collecting a series of images of a site, geographically referencing and mosaicing the images, measuring the distance between shoreline and stable ground features, and analyzing differences in those distances between years. Such comparisons can be conducted either manually or using most GIS or image analysis programs.

The remote sensing sampling interval would depend on the availability of images, going back to at least the first available air photos (ca. 1950) through present day. These analyses should be conducted at a minimum at all field monitoring sites, but also extending beyond field sites where possible to assess changes within and among various coastline classification types in a region. These types of remote analyses would also be effective for monitoring coastal change in areas of particular interest, such as an archeological site, environmentally sensitive habitats, defense or industrial infrastructure, and communities.

5.2.3. Secondary Data

A wide range of ancillary secondary data complements field surveys and remote sensing analyses. Meteorological data obtained from automated and conventional sites should be routinely appended as part of site background profiles. Material from permafrost boreholes, including lithological and stratigraphic descriptions also should be included. Historical sources include archival records such as both scientific and exploration journals, navigation charts, hydrographic charts and oral historical (anthropological) materials. Indigenous knowledge should be solicited both from the anthropological literature, as well as from local residents. Local communities can further provide data by videotaping storm events (before, during and after) and implementing field studies and maintaining field sites.

Stratigraphic investigations should be encouraged as a means of obtaining longer baseline data in order to assess erosion and deposition trends, beyond the 50 yr range available with aerial photogrammetry. Sites should be assessed in regard to Quaternary data sources and interpretations. Studies of long-term coastal change can be conducted by using aerial photos coupled with radiocarbon based chronologies that are keyed to stratigraphic sections (see Jordan and Mason,1999 for an example of the past 5000-year sea-level increase in Northwest Alaska). A variety of other proxy Quaternary data can elucidate shoreline and sea level changes; these include, paleo-pedology, palynology, and study of ostracodes, diatoms, and foraminifera, as well as other faunal and floral remains.

5.2.4. Recommendations for Monitoring Sites

Key sites will be identified throughout the circum-Arctic region for implementing a long-term monitoring program. A key site is defined as a site representative of a significant percentage of the coastline in the study region. Observational sites are areas where any information on coastal change is available to complement the key sites. Local communities and researchers could nominate their study sites for key sites, if the minimum criteria are met. The following criteria and steps would be employed for site selection and study:

Assess the availability of the above-mentioned data: Ideally, sites for which prior baseline survey data and/or ancillary data are already available would be eligible for selection as a key site.

Study area size: The minimum length of the shoreline to be studied at each key site is 300 m (length could be longer, depending on the type of coast to accommodate local variances). Within the 300 m, a minimum of three offshore/onshore profiles will be established perpendicular to the shore (see methods above).

Data standards: In order to eliminate differences among regional and national use of datums, all investigators should refer to the national sea level for conducting shoreline profiles. The WGS 84 map projection should also be used for the circum-Arctic coastal monitoring program. General information required for each site includes: date of survey; time and time zone; investigator(s); methods used; profile survey line orientation; status of ground control points; and ancillary data (e.g., photos, active layer measurements, core sampling, etc.).

Establish and document ground control points: It is critical to establish ground control points at stable features that are not expected to change through time. These ground points will provide a benchmark for all shoreline survey field work and remote-sensing analyses at the key site, and they must be easily located on the ground as well as from the air. Full documentation of the ground point location and description (e.g., GPS location, photograph, recognizable site features) is essential for relocating by different investigators over time.

Mappable parameters: To supplement the coastal classification and mapping effort, investigators at key sites should record the following qualitative categories for rate of change: rapid retreating, moderate retreating, slow retreating, stable, accumulating. Both key and observational sites should have detailed information stored in a database management system that can be keyed to map presentation.

A metadata form to identify and select key sites was developed after the workshop and the information required is presented in Table 5.2. The metadata forms would be come apart of the IPA Global Geocryological Database hosted at the NSIDC in Boulder, Colorado.

Table 5.2. Information to be included in a metadata form for Arctic Coastal Key Sections (draft 2/00)

COASTAL KEY SECTION NAME

COUNTRY AND REGION

LATITUDE AND LONGITUDE (degrees, minutes, seconds if available)

SECTION LENGTH (km)

OBSERVATIONAL PERIOD (years of observation, frequency of observation, etc.)

METHODS AND TYPES OF MEASUREMENTS

Onshore methods (GPS, theodolite, etc.)

Offshore methods (bathymetry, shallow seismic, etc.)

Remote sensing (aerial photographs, video, etc.)

SECTION MORPHOLOGY

Onshore (cliff height (m), cliff angle, local relief (m), etc.)

Offshore (shoreface profile, etc.)

GEOLOGY AND GEOCRYOLOGY (types of sediments for onshore and offshore, ice content and type, etc.)

DOMINANT SITE VEGETATION

METEOROLOGICAL CONDITIONS (air temperature, snow cover, wind speed and direction, frequency of storms, etc.; indicate frequency of observations)

OCEANOGRAPHIC CONDITIONS (sea level, tides, wave height, sea water temperature, currents, etc.; indicate frequency of observations)

ACCESSIBILITY OF COASTAL SECTION (Mode of transportation:helicopter, road, offroad vehicle, river, etc.)

NAME AND LOCATION OF CLOSEST CLIMATE STATION (latitude, longitude, and distance (km) from section; provide both meteorological and oceanographic data separately as available)

RESPONSIBLE INDIVIDUAL(S) AND ORGANIZATION FOR DATA COLLECTION (complete mailing address, email and fax addresses)

RELEVANT PUBLICATIONS (complete citation, use additional space)

SKETCH, PHOTO, VIDEO OF KEY SECTION (as available)

OTHER COMMENTS: (use additional space)

5.3. COASTAL PROCESSES

Participants: Felix Are (rapporteur), Hajo Eicken, Sathy Naidu, Vladimir Ostroumov, Andrey Proshutinsky, Erk Reimnitz, Igor Semiletov, Alexander Vasiliev, Hans Hubberten, Jess Walker.

Our tasks were to review dominant water- and ice-related erosional, transport and depositional processes; methods of measuring shoreface parameters and calculating profiles and coastal changes for major types of coasts; and recommend and/or select corridors or locations for permanent monitoring sites. There is a considerable body of literature on this subject ; see for instance Are (1988), Reimnitz and Barnes (1987), Solomon et al (1993), Hequette and Barnes (1990), Dallimore et al (1996).

5.3.1. Processes

Erosion processes include hydromechanical erosion of the shoreface, thermodenudation of the shoreface and cliffs with exposure and thawing of exposed permafrost, soil subsidence as a result of ground-ice melt both subaerially and subaqueously, and ice action. Accretion involves delta processes and coastal advance through marine deposition processes and beach formation.

Derivation of shoreline change with time is based on visual observations (including video) using remote sensing and, in particular, aerial surveys, supplemented by geodetic field measurements, to determine modern shoreline position. Measurement intervals need to be adapted to the specific climatic oscillation periods, catastrophic events and gradual change that are unique to the area being studied. Maximum extent of storm surges can be mapped by surveying elevations of driftwood lines. Morphodynamics of the shoreface are determined from echo sounding by single or multi-beam measurements, high-resolution seismics, and sediment sampling. Denudation rates can be derived using magnetic susceptibility to determine weathering stage. Further development of models to estimate and predict coastal changes are required (in particular with moving boundary conditions considering storm surges etc.). Improvement of tracer techniques are required to assess erosional/accretional regimes.

Sediment transport processes include: (1) hydromechanical transport (long-shore, cross-shore transport), rafting and gouging by sea ice and glacier ice; (2) riverine transport and, in particular, supply to delta environments; and (3) aeolian transport. Bedload sediment transport can be estimated using measurements of wave and current parameters and the use of sand traps and tracers. Estimation of suspended load transport (for non-cohesive sediments) is usually based on measurements of current parameters and concentration of suspended sediments. Estimates of sediment transport should be supplemented by measurements of particulate and dissolved organic matter.

A discussion on environmental parameters is presented in Section 5.5 and includes atmospheric, oceanographic, hydrologic, and sea-ice conditions.

5.3.2. Discussion

The breakout group discussed a number of issues that are summarized below.

In the context of the workshop goals, coastal processes are important in that they control the ultimate fate of sedimentary particles, organic carbon and nutrients that are derived from coastal sources. The process group also discussed state-of-the-art methods for measurement of these parameters as a first step in the planning of future investigations.

Release of dissolved and particulate matter to the Arctic Ocean is relevant to the question of climate change, and removal of sediments from shelf. Since, in many locations, the inner shelf is a non-depositional environment, there is a need for more information regarding the following:

(1) the role and importance of ice rafting, along-shore transport and wave-induced transport for evolution of shoreface,

(2) the influence of coastal erosion on the fate of organic carbon and its effects on release of greenhouse gases and nutrient supply, and

(3) the impact of processes on native communities and benthic communities (issue of "bio-erosion")

There is a need for the assessment of the importance of shoreface processes vs. shelf processes (width of zone?) and the role of ground ice warming/melting as a result of atmospheric warming (including lengthening of summer), enhanced transfer of heat (warming and lengthening of open-water season) and energy (increase in storm frequency).

Should mapping and selection of monitoring sites be based on subdivision of geological setting rather than on territorial divisions; categories of erosion and accretion could be basis for further work?

During the plenary discussion the following points were raised:

(1) will there be a problem in extracting relevant parameters from existing data bases,

(2) rate of sea level change should be included in the database (these data are compiled and processed at AARI),

(3) the paper by Hequette and Barnes (1990) should be reviewed for the correlation between rate of coastal retreat and different parameters describing type of coast and wave energy.

5.4. GROUND-ICE ESTIMATES AND MAPPING

Participants: Wayne Pollard (rapporteur), Jerry Brown, Nicole Couture, Larry Dyke, Steve Forman, Marina Leibman, Vladimir Romanovsky, Nikolai Romanovsky, Yuri Shur, Irina Streletskaya, Martin Stromner.

An estimate of excess ground-ice volume in eroding shorelines is required for computing sediment production. Figure 2.1 illustrates the equations which include the ice volume term (v1).

In order to estimate sediment yields from eroding ice-rich permafrost coasts, the group responded to the following questions:

- What are the methods used to estimate ground ice content (volume)?
- What confidence levels do different data sources allow?
- How do we represent ice content data?
- How do we map ice content estimates at different scales?

5.4.1. Methods for Estimating Ground-ice Content

We developed a hierarchy of data sources for ground-ice evaluation and attempted some level of assessment of confidence (for now simply High and Low). Methods are divided into direct and indirect observations and specific levels of confidence are assigned to the direct methods (Table 5.4.1). The confidence levels of the overall method are rated as either High or Low, based on the confidence number of the direct method and whether it is supplemented by any secondary, indirect method. If only an indirect method is used, it will be rated as Low. However, Scott et al. (1990) have provided an assessment of the accuracy of different geophysical techniques for detecting ground ice; therefore, the confidence levels of the indirect methods may be revised in subsequent discussions.

For example, data from a large natural exposure with a confidence level of 5 would receive a High rating. Data from shotholes alone would have a confidence level of 2 and would receive a Low rating. If the shothole data was supplemented with data from a secondary source such as geophysics, its confidence level would increase to 3 and it would be rated as High. The confidence levels and the method(s) used to estimate the ground ice content (identified by the letter labels) will be included in the database associated with the map of visible ground ice (see section 5.4.2).

Table 5.4.1. Methods for Estimating Ground-Ice Volume

METHODS				
Direct measurements			**Indirect measurements**	
Map Label	**Type**	**Confidence level**	**Map Label**	**Type**
A	Large natural exposures	5	a	Graphic (video, still, historical of natural exposures) Photogrammetric
B	Boreholes/cores (single, multiple, using geophysics)	3-4	b	Geophysics (seismic, GPR, EM, electrical resistivity, gravity)
C	Shotholes	2-3	c	Terrain analysis (thermokarst features,ice wedge polygons, frost heave, slopes processes)
D	Limited Exposures	1-2	d	Satellite remote sensing

5.4.2. Ground-Ice Classification for Mapping

In our discussions, we had to come to terms with different approaches used in North America and Russia. We recognize that all forms of ice are important including massive ice bodies, wedge ice, pore ice, ice complexes (fully penetrated by large ice wedges), injection ice, etc. A useful Russian approach simply identifies ice as either regular (ice wedges) or irregular (tabular ice, injection ice, etc). For our classification, we decided that an important distinction lies between wedge ice and ice bodies (corresponding to the regular and irregular idea). We proposed this limited level of detail for purpose of estimates and mapping. Additionally, we identified the following parameters as critical for mapping visible ground ice: depth ranges, percentage volumes of visible ice, grain size/lithology, and porosity.

The classification scheme illustrated in Table 5.4.2 is the key for mapping of ground ice. It is designed to be used in conjunction with an average visible ice content. Visible ice is synonymous with excess ice. In any one section, the percentage volume of ice vs. soil is determined and assigned a value of low (0-20%), medium (20-50%), or high (>50%). If the permafrost is dry or if bedrock is present, it is specifically noted. Because ground-ice content can vary significantly with depth, estimates are given for an upper and a lower layer. It would be ideal to include more layers, but it was felt that more than two would result in a map that was too cumbersome. The division between the upper and lower layers can vary with each map unit. It is based on where the greatest natural variation occurs within the entire section. If dry permafrost or bedrock is present, it will constitute a layer unto itself and the remainder of the material in the profile will constitute the other layer. We propose the inclusion of 2 symbols (may be more in the future) which help clarify the relative presence or absence of ice wedges (denoted by V) and ice bodies (denoted by =).

Table 5.4.2. Visible/Non-visible Ground-Ice Classification

VISIBLE ICE				**NON-VISIBLE**	
Depth	**Low 0-20%**	**Medium 20-50%**	**High 50+**	**Bedrock**	**Dry**
Upper	UL	UM	UH	Ubr	UD
Lower	LL	LM	LH	LBr	LD

An example of a map unit designation is ULLH27V=. This unit consisits of low visible ice in the upper part of the section, and high visible ice in the lower part of the section. The total visible ice content is 27 % (see generalized section), and includes ice wedges and an irregular ice body (i.e. massive tabular ice or pingo ice)

5.4.3. Ice-Content Compilation

In order to input a single ice-content value for a map unit it is necessary to convert stratified data into a representative unit value. We propose doing this within a data base that forms part of the map. This involves development of a data protocol which can be accessed for more detailed analyses and for improved interpretation of data for any particular map unit.

The raw database is analyzed to produce a generalized vertical cryolithological section for each map unit. The generalized section is based on layer thickness.

An important point to remember is that the visible ice content value represents a weighted sum based on averages for several actual ice-content profiles. The step-by-step procedure for estimation of visible ice content follows:

1. The raw database is compiled and includes method of determination, assessment of data confidence, layer-by-layer logging.

2. The raw database is analyzed to produce a generalized vertical cryolithological section based on layer thickness, lithology, ice content, ice types, method used for estimate and confidence level, and this information is entered into a template (Table 5.4.3). The number of layers will depend on the detail available in the raw data and the actual material changes in the stratigraphic profile (for now a maximum of ten layers is proposed for input to the template).

3. Each generalized layer receives an assigned value of visible ice volume based on statistical averaging of constitutional excess ice content and addition from massive ice (ice wedges and irregular ice bodies). For instance, in the example below, 5% of the visible ice in the 0-5 m range is from constitutional ice, while 1% is from wedge ice. The total visible ice volume for the layer is therefore 6%. In the 5-15m layer, all the visible ice is due to constitutional ice (total of 10% for that layer). In the 15-20m layer, 20% of the visible ice is due to constitutional ice, while 60% is due to massive tabular ice, for a total of 80% visible ice for this layer. The visible ice in each layer is weighted by the layer thickness to arrive at a total visible ice volume for a unit area of the entire 20m deep section.

$$\text{Total visible ice volume} = \frac{(5\text{m} \times 6\% + 10\text{m} \times 10\% + 5\text{m} \times 80\%)}{20\text{m}} = 26.5\%$$

4. Based on the classification developed earlier, a map unit that contained this vertical section would be mapped as having a medium visible ice content, since the total visible ice is between 20% and 50%. The size of the map unit will vary, depending on the availability of data for the region and the degree of generalization used in producing the vertical section.

The upper 0-5 m zone usually corresponds to the permafrost that is characterized by modern (Holocene) processes and includes modern wedges. We propose that the upper younger zone always constitute a separate layer, regardless of whether its properties are actually distinct from the underlying layer. This will enable easier comparisons to be made between map units. Porosities used to define the saturated moisture contents beyond which ice contents are in excess of saturation and, therefore, constitute visible (excess) ice are for sand (35%), silt (40%), clay (50%), organic (80%).

Table 5.4.3. Example of Database Template

Layers	Lithology	Method of Estimate	Confidence	Visible ice volume, %	Total	Ice bodies (Massive ice)
0-5 m	Sand	1	High	5+1	6	Ice wedges
5-15 m	Silt	1	High	10	10	No
15-20 m	Clay	3B	High	20+60	80	Tabular ice

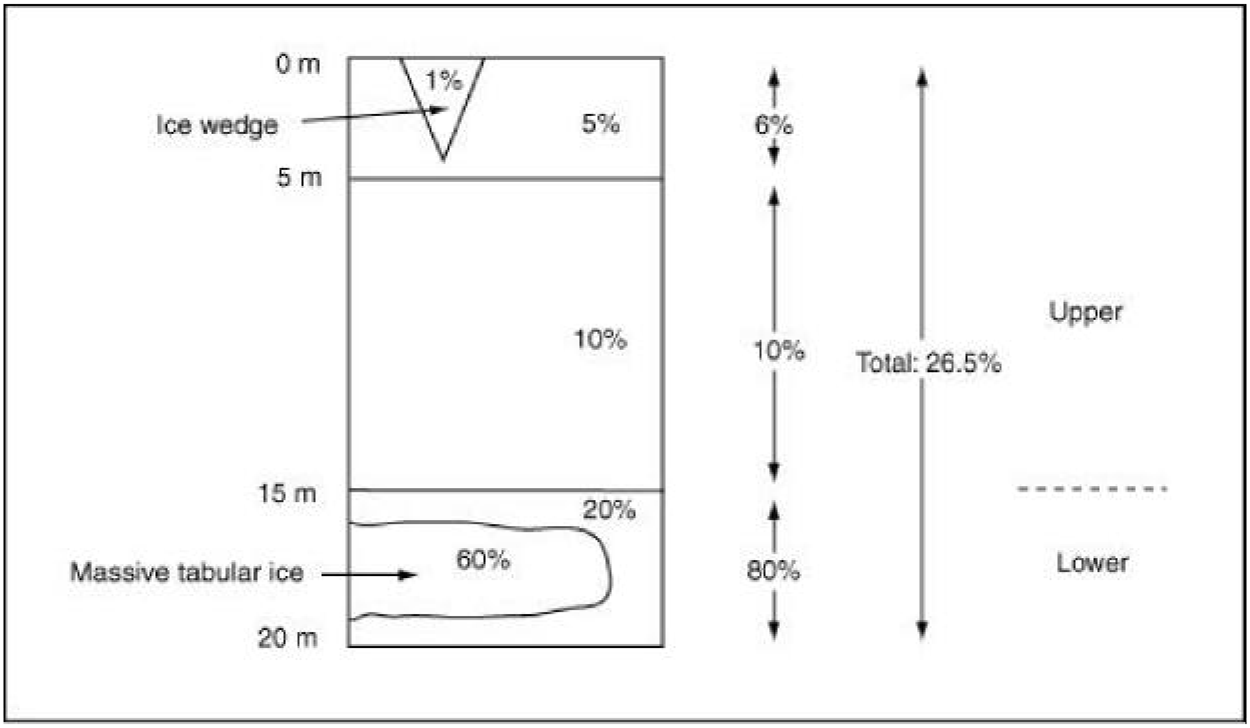

Figure 5.4.1. Method to estimate total excess ice volume in a multi-layer section based on values representing weighted sum of averages.

5.5. ENVIRONMENTAL DATA REQUIREMENTS

The following data and information requirements were developed in the Coastal Processes breakout group and is reported in this separate section as its contains data applicable to several other sections.

5.5.1. Atmospheric Conditions

Standard wind parameters: frequency distribution of wind speed and direction (wind rose) as well as frequency distribution for strong winds (>10 m s^{-1}) based on synoptic weather station data (6-hour to daily intervals). Data sources: weather stations reporting to World Meteorological Organization (WMO, available through U.S. National Climatic Data Center (NCDC), reanalysis data fields from the U.S. National Center for Environmental Prediction (NCEP) or the European Center for Medium-Range Weather Forecasts (ECMWF).

Positive/negative degree days: compute the sum of daily ground-level air temperatures for summer period (temperatures >0 °C) and for winter (temperatures <0 °C). Data from either synoptic weather stations or medium-range forecast reanalysis data (same sources as for wind parameters).

Standard storm parameters:

Number of cyclones per year (or season) based on sea level-pressure data obtained from (re)analysis data (data source: NCEP, storm-track atlas from Institute on Climate and Planets at NASA Goddard Institute for Space Science; see Serreze, 1995).

Fetch: total length of open water between coast and ice edge or other landmass along principal wind direction; compute fetch distribution for open-water season based on wind-rose data (see above) and maximum distance to ice edge data (see below).

Precipitation: total snowfall and total liquid precipitation; data based on atmospheric circulation model results or snow accumulation databases (e.g., Russian snow accumulation data base available through U.S. National Snow and Ice Data Center (NSIDC)).

Spacing of data points along coast: Data point spacing should be based on resolution of the respective data sets (50 km for standard sea-ice concentration maps, 50 to 100 km for GCM grid cells determining reanalysis data).

5.5.2. Oceanographic Conditions

5.5.2.1. Current regime

Summary currents in arctic seas are composed of permanent, wind-induced, and tidal currents.

Permanent currents: seasonal variability of the surface and bottom currents (monthly mean) direction and speed. Space resolution is 50 km. Sources: RSMOT [1993], Atlas Arktiki [1985], Atlas Okeanov [1980], Proshutinsky et al. [1995], and International Northern Sea Route Project (see http://www.ims.uaf.edu:8000/insrop-2/).

Wind-driven currents (surface): frequency distribution of current speed and direction (current rose). Maximum currents and their statistics including probability of occurrence of maximum speed. Probability of occurrence of direction of maximum currents. Some information is available from Proshutinsky et al. [1995] (see http://www.ims.uaf.edu:8000/insrop-2/). Wind-driven circulation models can be used to simulate wind-driven currents (including intermediate water and bottom layers) based on wind statistics (Proshutinsky, 1986, 1993, 1995).

Tidal currents: maximum tidal currents, ellipses of tidal currents, residual tidal currents. Major sources: Kowalik and Proshutinsky [1993, 1995], gridded data with a space resolution of 14 km for 8 tidal waves is presented at: http://www.ims.uaf.edu:8000/tide.html (see instructions how to access tidal data base).

5.5.2.2. Storm surge parameters and wave regime.

Sea level and storm surges: Probability of occurrence (monthly) of sea level heights greater than 50 cm, 100 cm, 150 cm etc. with a space resolution of 50 km. Statistics of duration of storm surges. Statistics of combination of storm surges with drifting ice. Sources of information: Proshutinsky, 1993, 1995, http://www.ims.uaf.edu:8000/insrop-2/. Storm surge statistics can be simulated using storm surge models of the arctic seas and 6 hour atmospheric pressure fields described above.

Wave regime and ice concentrations: These parameters include probability of occurrence of waves heights and wave direction. Special attention should be paid to the statistics of combination of high wind wave and heavy ice with concentration of 30-50% (ice storm conditions). Sources of information: RSMOT [1993], Atlas Arktiki [1985], Atlas Okeanov [1980], Proshutinsky et al. [1995], and International Northern Sea Route Project (see http://www.ims.uaf.edu:8000/insrop-2/).

5.5.2.3. Water temperature and salinity.

Seasonal variability of water temperature and salinity with a space resolution of 50 km. Sources of information: Atlas Arktiki (1985), Atlas Okeanov (1980), Proshutinsky et al. (1995), and International Northern Sea Route Project (see http://www.ims.uaf.edu:8000/insrop-2/), EWG (1997,1998), Morley, R. and

M. Steele, (1999; The Polar Science Center Hydrographic Climatology (PHC), a global physical oceanographic atlas at : http://psc.apl.washington.edu/Climatology.html).

5.5.3. Hydrologic Conditions

Fluvial water input: seasonal means of water discharge at river mouth. Data obtained from Global Runoff Data Center (GRDC) in Koblenz, or Pan-Arctic Hydrologic Database (University of New Hampshire (Charles Vorosmarty) and Cort Wilmont, University of Delaware; see also Gordeev et al., 1996).

Fluvial sediment input: annual mean supplied at river mouth. Data to be obtained through National Hydrological Data Centers or possibly from runoff/discharge models (Gordeev et al., 1996).

Break-up date: date of initial river-ice break-up during spring flooding. Data to be obtained through National Hydrological Data Centers (for Lena and other rivers draining into Laptev Sea, see Bareiss et al., 1999).

5.5.4. Sea-ice Conditions

Freeze-up dates: determine start of freeze-up based on identification of local minimum in ice extent record prior to autumn decrease in open water. Iice extent data based on passive-microwave satellite data (available through NSIDC, or ice-chart databases (digitized Russian ice charts, available through NSIDC, or digitized ice charts from the U.S. National Ice Center (NIC).

Break-up dates: determine start of break-up based on time series of ice-concentration data (same as that listed above for freeze-up dates).

Width of bottom-fast ice zone: distance between shore and bottom-fast ice edge in mid-winter; due to lack of direct measurements parameterization based on distance between shore and 2-m isobath.

Distance to (1) ice edge (in summer) and (2) polynya (in winter):

(1) Distance between shore and ice edge (as defined by 15% ice concentration contour) during summer minimum ice extent (or alternatively for fixed date, e.g., September 1). Ice edges derived from passive-microwave satellite data or digitized Russian or NIC ice charts.

(2) Distance between shore and margin of polynya (if present, based on nearest locations) in mid-winter. Polynya data from digitized ice charts, possibly derivation from passive microwave data or AVHRR (Pathfinder) data.

Ice-storm probability: number of occurrences of ice storms (motion of brash ice and floe fragments in wave field onto beach during storm) per year or season. Data derived from model output (cf. database compiled by Andrey Proshutinsky).

Access to databases on the World Wide Web:

GRDC (hydrological data): http://www.bafg.de/grdc.htm

NCEP (reanalysis data): http://www.cdc.noaa.gov/ncep_reanalysis/

NCDC (climate data): http://www.ncdc.noaa.gov/

NSIDC (sea-ice, meteorological and hydrological data sets): http://www-nsidc.colorado.edu/index.html

International Northern Sea Route Project : http://www.ims.uaf.edu:8000/insrop-2/

Polar Science Center Hydrographic Climatology (PHC), a global physical oceanographic atlas: http://psc.apl.washington.edu/Climatology.html.

Currents: http://www.ims.uaf.edu:8000/insrop-2/

R-arcticnet database: http://www.R-arcticnet.sr.unh.edu/

5.6. COMMUNITY-BASED COASTAL MONITORING PROGRAM

Participants: Douglas Anderson (rapporteur), Caroline P. Cannon, Julie Esdale, Anna Klene, Mae R. Hank, Benny Lane, Loren Litchard, Owen Mason, Sue Mitchell, Vladimir Pitulko.

The group modified the original scope and title (Cultural and Economic Implications) and focused attention on the development of standards for community-based monitoring of coastal processes, focusing on coastal hazards to Arctic communities.

5.6.1. Introduction

Participation of Arctic residents in the planning and conduct of research in the Arctic is part of arctic policy. For that reason the U.S.-sponsored workshop invited both senior-level officials and students from the U.S. Arctic to participate in the workshop. The group specifically recommended that a community-based monitoring protocol be included in the international arctic coastal dynamic research program.

The community-based monitoring group considered ways by which studies of coastal processes can assist Arctic coastal villages to recognize and deal with the environmental hazards that confront them. A key to our approach was to examine ways in which the long-term expertise of local residents can be brought to bear on both the data collection and the monitoring of coastal processes in and around the villages. Several advantages of a community focus are that: 1) monitoring observations can be undertaken throughout the year and from year to year, 2) monitoring can be achieved at a lesser cost since travel expenses are minimal. 3) local observations can identify relevant additional environmental variables that may not have been considered in prior research designs, and 4) a monitoring program can assist local mitigation efforts.

We have organized our comments around criteria to be considered for a successful monitoring program, general procedural issues, and specific suggestions for conducting the program.

5.6.2. Criteria and Goals

The monitoring program must be set up to insure consistency in data collection, continuity in monitoring, and dissemination of observations. A protocol for communication (fax, email) between community observers and local or regional researchers must be established at the outset.

A set of criteria for monitoring coastal processes should be established that addresses the needs of both the local and scientific communities. Data collection procedures must be community based, with training targeted to long-term local residents.

The training and instrumentation must be appropriate to village level capabilities. Particular care must be taken to insure long-term monitoring and data collection. Programs such as GLOBE can be used by students to enter data and exchange observations and information.

A long-term goal is to develop an inclusive list of coastal threats to arctic communities. This could begin within particular regions, but eventually should be expanded to encompass the entire circum-Arctic region.

A related goal is to assemble representatives from specific regions to prioritize coastal hazards and threats to local natural and cultural resources. This list will serve as a basis for establishing the relevant variables to monitor. In northwest Alaska, these variables pertain primarily to erosional processes. In other areas, such as river deltas, etc., depositional factors may be especially important.

5.6.3. Community-level Site Selection

This program should be inclusive in nature, such that all interested communities are welcomed. Communities in regions where little coastal research has been conducted might be encouraged or invited to participate. Initially, we suggest an opportunistic site selection approach, targeting 2 or 3 communities in which we have particular knowledge and/or representation. In Alaska, Point Hope and Barrow are logical sites for the initial stage. Radio or other media may be helpful in soliciting the participation of additional communities. The interested communities could form the base from which Key Sites could be selected. The number and placements of monitoring stations should be selected with a view toward the scale of the problem and the complexity of the coastline.

The program would benefit from the participation of high school students in data collection. Students would benefit both by learning scientific methodology and by enhancing their credentials on college applications. One drawback to using students is a potential lack of continuity, since many of the village teachers remain in a particular village for only 2 or 3 years. In all cases a long-term local resident liaison or “point person” must be identified to oversee data collection and monitoring. Ideally this person would be responsible for training new teachers and student or resident participants. Requests for research funding by academic investigators in the specific regions should include remuneration for this type of position.

5.6.4. Implementation

The first step to implement the program is the development of a handbook of procedures to be distributed to participant communities. One option is to use the handbook that is being developed by the Geological Survey of Canada, and, modify it for a general audience. The handbook would include a description of procedures that would include: keeping laboratory or log/field books; a standardized method of measurement techniques (using the metric system); recommended spatial intervals to use in establishing monitoring stations; temporal intervals at which to collect data (regular intervals plus a particular events like storms); and possibly procedures for entering data into computers. In addition to collecting quantitative data, monitoring data should also include qualitative observations of the effects of storms, floods, breakup processes, etc. Video taping of particular events and standardized interviews of residents who witness various coastal processes would be important components of the program.

The second step is selecting sites for the monitoring stations. This step requires coordination between local residents and the scientific community. Installation would include establishing pairs of permanent fixed points in tandem, perpendicular to the beach. Periodic measurements would be made from these stations to the retreating coastal margin (see Section 5.2.4). Intervals between these erosion monitoring stations would be determined by site-specific conditions and community concerns.

6.0. FINDINGS AND RECOMMENDATIONS

High-latitude coastlines, dominated by cryological processes, are sensitive to climate variations. Accelerated sea-level rise, thermokarst and thermal erosion, combined with reduced sea-ice extent and more energetic wave climate pose unique challenges and create significant vulnerability for human communities and living resources in the Arctic. Furthermore, recognition of impacts requires measurement of past, present, and future rates of changes in shoreline position and biophysical processes. Therefore, the workshop participants recommend that:

- The associated coastal impacts and adaptations should be appropriately recognized in the forthcoming Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and by national and international organizations.
- A concerted and coordinated international data synthesis and mapping effort is required to properly assess the magnitude of sediment derived and transported from the coast onto the shelf.
- Furthermore, there is a need to prepare a synthesis of existing data and information concerning fluvial sediment inputs to the Arctic shelves and basins.
- An international network of representative key and observational sites is required for assessing long-term changes, including threats to local communities, habitat modifications, and carbon and sediment budgets.
- A local community-based monitoring protocol should part of an international research and monitoring design with observations conducted by Arctic residents.

7.0. FUTURE ACTIVITIES

International planning, cooperation and funding of national, bilateral and multi-national projects are required to accomplish the following:

1. Develop a circum-Arctic monitoring network of key and observational sites based on a metadata inventory of potential regional sites (distribution of sites and initial responsibilities would be distributed in each regional sea illustrated in Figure 4.1 and Table 4.1).

2. Construct databases for web-based delivery.

3. Apply the coastal classification to representative sites.

4. Develop circum-Arctic map products of coastal sediment yields, climate change sensitivity, severity of environmental forcing, etc.

5. Explore and develop international cooperation and projects with other organizations including the International Arctic Science Committee (IASC) and its regional programs including BASIS, BESIS, LOIRA, Intergovernmental Oceanographic Commission (IOC), International Hydrographic Bureau (IHB), IGBP-Land-Ocean Interaction in the Coastal Zone (LOICZ), the Arctic Ocean Sciences Board (AOSB) program on Arctic Paleo-Discharge (APARD), and IGU commissions.

6. Convene workshops periodically to assess progress and facilitate the development of specific activities.

Postscript: During the IASC Council meeting in Cambridge, UK, April 2000, the Arctic Coastal Dynamics (ACD) program was approved as joint IPA-IASC activity. The next step is consultation with other programs (see 5 above) and preparation of a draft Science and Implementation Plan.

8.0 RELEVANT ACRONYMS

AARI	Arctic and Antarctic Research Institute
ACD	Arctic Coastal Dynamics
ACIA	Arctic Climate Impact Assessment
AOSB	Arctic Ocean Sciences Board
APARD	Arctic Paleo-Discharge
ARCUS	Arctic Research Consortium of the United States
ARCSS	Arctic System Science
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radimeter
AVHRR	Advanced Very High Resolution Radiometer
CTD	Conductivity, Temperature, Depth profiler
ECMWF	European Center for Medium-Range Weather Forecasts
ENVI	Environment for Visualizing Images
ERDAS	Image processing software manufacturer
ETH	Enhanced Thematic Mapper
FWS	Fish and Wildlife Service
GDA	GEBCO Digital Atlas
GEBCO	General Bathymetric Chart of the Oceans
GGD	Global Geocryological Database (IPA)
GHAAS	Global Hydrological Archive and Analysis System
GLOBE	Global Learning and Observation to Benefit the Environment
GPS	Global Positioning System
GRDC	Global Runoff Data Center
GSC	Geological Survey of Canada
HRV	High Resolution Visible
IASC	International Arctic Science Committee
IBCAO	International Bathymetric Chart of the Arctic Oceans
IGU	International Geographical Union
IHB	International Hydrographic Bureau
INTAS	Independent association formed by the European Community
IOC	Intergovernmental Oceanographic Commission
IPA	International Permafrost Association
LOICZ	Land-Ocean Interaction in the Coastal Zone
MMS	Minerals Management Service
MSU	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
NCDC	National Climatic Data Center (U.S.)
NCEP	National Center for Environmental Prediction (U.S.)
NIC	National Ice Center (U.S.)
NIMA	National Intelligence Mapping Agency
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSIDC	National Snow and Ice Data Center
NTM	National Reconnaissance Imagery
PAN	Panchromatic Sensor
RAISE	Russian-American Initiative on Shelf-Land Environments
RSMOT	Russian State Ministry of Transport
SAR	Synthetic Aperture Radar
TM	Thematic Mapper
USGS	U.S. Geological Survey
VNIIOceangeologia	All-Russian Research Institute for Geology and Mineral Resources for World Oceans
WGS 84	World Geodetic System 1984
WMO	World Meteorological Organization
WVS	World Vector Shoreline

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APPENDICES

RAISE WORKSHOP

ARCTIC COASTAL DYNAMICS

2-4 November 1999

Marine Biological Laboratory
Woods Hole, Massachusetts

AN INTERNATIONAL WORKSHOP ON

ARCTIC COASTAL DYNAMICS

NOVEMBER 2–4, 1999

JERRY BROWN, WORKSHOP ORGANIZER

MARINE BIOLOGY LABORATORY
WOODS HOLE, MASSACHUSETTS 02543

An International Workshop on Arctic Coastal Dynamics
November 2-4, 1999
Marine Biology Laboratory
Woods Hole, Massachusetts 02543

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Monday, November 1
MBL Swope, Meigs Room

	Local sightseeing and tours to be announced for early arrivals
6:00 p.m.	Buffet reception

****

Tuesday, November 2
MBL Swope, Meigs Room

7:00–8:15	Breakfast (Swope Cafeteria)
8:30–9:00	Opening Session
	Welcomes: John Burris, Director, MBL, and Deborah Hutchinson, U.S. Geological Survey
	Introductions and Workshop Overview: Jerry Brown, IPA, and Steve Solomon, Geological Survey of Canada
9:00–10:15	Invited Presentations (Meigs Room)
	Don Forbes: *Field techniques for measuring and mapping high latitude coasts*
	Hajo Eicken: *Applications of remote sensing to Arctic coastal monitoring and mapping*
	Mikhail Grigoriev and Volker Rachold: *Computer techniques for measurement of coastal retreat*
10:15–10:45	Break (group photograph opportunity)
10:45–noon	Invited Presentations continue
	Erk Reimnitz: *Ice processes: video presentation*
	Felix Are, Erk Reimnitz and Steve Solomon: *Shoreface profiles of high latitude coasts*
	Steve Solomon: *Circum-arctic coastal mapping and classification of high latitude coasts*
	Discussion of presentations
Noon – 1:15	Lunch (Swope Cafeteria)
1:15–3:30	Discussion (Meigs Room): Review workshop objectives and tasks for breakout groups (see attached). Discuss input requirements (data types, formats, holdings, availability, and incorporation of information onto maps), designate leaders and begin individual groups sessions:
3:30–5:30	Break followed by poster presentations (group photograph opportunity)
5:30–7:00	Reception and dinner (Swope). Evening free to talk, walk and visit local pubs.

Wednesday, November 3

MBL Swope Meigs Room

7:00–8:15	Breakfast (Swope Cafeteria)
8:30–10:00	Plenary session: Presentations and review status of breakout groups
	Steve Forman: Report of the recent workshop *“Assessing impacts of arctic bathymetry changes and fresh water inputs on shelf and ocean circulation for the past 20,000 years*”
	Richard Lammers and Bruce Peterson: *Assessment of contemporary arctic river runoff based on observational discharge records and the Pan Arctic Hydrology project.*
10:00–10:30	Break
10:30–noon	Meeting of breakout groups (Meigs Room, and upper lobby areas)
Noon–1:00	Lunch (Swope)
1:00–1:30	Plenary session: Status reports
1:30–5:15	Continue group meetings with break at 3:15.
5:30–7:00	Reception and dinner (Swope). Evening free to talk, walk and visit local pubs.

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Thursday, November 4

J. Erik Jonsson Woods Hole Center of the National Academy of Sciences
All meals in Hackerman House, Jonsson Center.
Cars and van leave from Swope starting at 7:15 a.m. (10-minute drive)
and return after evening banquet

7:30–8:15	Breakfast
8:30–10:00	Plenary session (Clark Carriage House)
	Progress reports and discussion
10:00–10:30:	Break
10:30–noon	Groups continue, compile information and data on maps as appropriate and prepare summaries; individual meeting rooms
Noon–1:30	Lunch, fresh air, and group photograph opportunity
1:30–3:00	Individual and/or joint group meetings to reduce overlaps; prepare oral reports
3:00–3:30	Break
3:30–5:15	Final plenary session (Carriage House)
	Reports, conclusions and discussion of future plans
5:30	Joint reception and banquet (clam bake) with RAISE Steering Committee
	Return to Swope by cars and van

****

Friday November 5, MBL Swope Meigs Room

7:00–8:15	Breakfast (Swope Cafeteria)
	Departures
	Synthesis Group remains for report preparation.
8:30–5:00	RAISE International Steering Committee Meeting

WORKSHOP OBJECTIVES AND ORGANIZATION

The proposed workshop objectives are:

1) Develop a common classification system for coastal mapping in the Arctic for purposes of estimating coastline sensitivity to change and erosion potential;
2) Identify and describe techniques presently used for coastal mapping and erosion measurements in the Arctic, and develop a standardized set of tools and techniques; and
3) Develop estimates of erosion rates for representative circum-Arctic coastlines.

The workshop's primary sponsor is the U.S. National Science Foundation and its Arctic program "Russian-American Initiative on Shelf-Land Environments (RAISE)". An NSF grant was awarded to the American Geophysical Union to conduct the workshop and provide partial travel and local support. In order to insure a well-balanced venue and participation, a small International Organizing Committee was formed and consists of: Felix Are (Russia), Jerry Brown (USA), Volker Rachold (Germany), and Steve Solomon (Canada). Jerry Brown and Bruce Peterson (MBL) serve as local organizers. The workshop is organized under the auspices of the International Permafrost Association, its Coastal Subgroup chaired by Steve Solomon, and the Working Group on Coastal and Offshore Permafrost, Cochaired by Hans Hubberten (Germany) and Nikolai Romanovskii (Russia). Among the approximate 50 participants are a number of graduate students and agency representatives from both the U.S. and Canada, several Alaskan natives including two high school students from Barrow and residents of Point Hope.

The following breakout groups and tasks are proposed:

Mapping and Classification

Review coastline classifications and agree upon the most appropriate one for purposes of mapping and estimating erosion, sediment yield and deposition. Develop a list of annotated attributes for GIS-based, circum-arctic mapping at 1:1,000,000. Recommend mapping approaches to assess long-term impacts related to sea level changes, loss of habitats and archeological sites, and onshore-offshore construction, among others.

Erosion Methodology

Review methods for measuring changes in coastline including ground surveys (transects, point measurements), comparisons of aerial, video, satellite and ground photographs, navigational and other maps and historical records. Recommend standard procedures for establishing long-term monitoring sites including ground, airborne, and space observations (e.g. GPS, lidar, radar, video, etc).

Coastal Processes

Review dominant water- and ice-related erosional, transport and depositional processes, methods of measuring shoreface parameters, and calculating profiles and coastal changes for major types of coasts. Recommend field and computational methods. Recommend and/or select corridors or locations for permanent monitoring sites.

Ground Ice Estimates

Review methods for estimating ground ice content (boreholes and shotholes, geophysical, photographic/video interpretation, thermokarst, thaw lake depths, etc). Develop range of estimates for mapping at different scales and landscapes and recommend method for calculating ice volumes. Revise or validate estimates of ground ice along circum-arctic coast on 1:1,000,000 to 1:10,000,000 maps.

CULTURAL AND ECONOMIC IMPLICATIONS

Describe implications and impacts resulting from erosion, sedimentation and inundation; both present and in the future, including loss of private and public lands, habitats, and archeological and cultural resources. Provide examples of methods for mitigation and current practices including offshore developments and coastal protection.

COMMON TASK

Environmental Data: Review and compile lists of available and future ground- based and satellite data and products required for coastal monitoring including bathymetric surveys, altimetry, land and sea climates, sea ice, tides.

Annotate computer generated strip maps with available site information and erosion and accretion estimates. Participants were requested to bring data (digital or paper products) that can be incorporated into a circum-arctic coastal database. Data is acceptable in virtually any form, but digital data is most easily incorporated into the map products and databases we plan to produce.

Data and information types include:

- Measured erosion rates.
- Profiles (shoreface, beach and cliffs).
- Maps showing ice content, coastal materials, coastal morphology.
- Environmental data on the distribution of sea ice, winds, waves, currents and storms along high-latitude coasts, and information on distance to 2 m, 5 m and 10 m contours.
- Open and gray literature citations (with geographic coordinates).

Digital profile data should be include (1) Distance from shore, water depth or elevation; or (2) Geographic coordinates, water depth or elevation. Information for vertical datum (e.g. mean sea level, chart datum, water level at time of data collection) should be included, along with a map of the location and coordinates of the start point and bearing of the profile line. If geographic coordinates are supplied, the projection and datum should be supplied.

BACKGROUND FROM WORKSHOP PROPOSAL

Arctic continental shelves comprise 30% of the area of the Arctic Ocean and contribute about 20% of the world's continental shelf area. This extensive circum-Arctic coastal margin is the interface through which land-shelf exchanges are mediated. Though generally only a few kilometers wide (except in the vicinity of large deltas), the coastal zone of the Arctic Ocean is the site of dramatic changes in not only the land and ocean but also in the cryosphere and biosphere. The Arctic coastlines are highly variable, can be stable or extremely dynamic and are the site of most of the human activity that occurs at high latitudes. Extraction of natural resources occurs in many locations around the Arctic Ocean creating the need for port facilities and the potential for pollution. These pressures are only likely to increase with time.

Models predict that global increases in carbon dioxide will cause warming in the high latitudes and changes in timing and amounts of precipitation. Secondary effects include changes in timing of freeze-up and break-up of ice, ice volumes and movement, sea level and discharge from large rivers, and breakdown of hydrates releasing greenhouse gases. The combined impacts of these primary and secondary effects on sediment (along with carbon and associated dissolved and particulate materials) delivery to the coast could be very large. There will likely be an impact on global carbon budgets since continental margins are the most important locations in the ocean for sequestering organic carbon (e.g. Berner 1982; Romankevich 1994; Smith and Hollibaugh 1993) and the “burndown” of carbon in marine sediments influences the global cycling of many other elements (e.g. Christensen, 1994).

An understanding of the sediment budget and transport rates and mechanisms along high latitude coasts is critical for the interpretation of the geological history of the shelves and for predictions of future behavior under the range of climate change scenarios (Wolfe et al., 1998). International programs such as the Russian-American Initiative on Shelf-Land Environments in the Arctic (RAISE), Land-Ocean Interaction in the Coastal Zone (LOICZ) and Arctic Paleo-Discharge (APARD) require a better understanding of the relative roles of rivers and coasts in providing sediments and organic carbon to the shelf. For example, RAISE has identified the need to quantify organic matter and nutrient fluxes from both rivers and coastal erosion in order to understand carbon cycling and coastal responses to rapid climate changes. The importance of many of these issues (among others) was also identified during a joint workshop on Arctic coastal processes held by the USGS and the GSC in 1990 (Taylor and Barnes, 1990). In addition, the workshop called for an international meeting on Arctic coastal processes and publication of summary papers on our state of knowledge.

Need for International Synthesis

While local or regional scale investigations have provided some insight into high-latitude sediment budgets, no attempts have been made to synthesize and expand them to encompass the circum-Arctic region. As an initial step, establishment of international standards for mapping and measuring high-latitude coasts and their dynamics is required in order to investigate the role of shoreline processes (erosion, transport) in the circum-Arctic sediment budget.

Data on sediment inputs from coastal erosion exist from portions of the Beaufort Sea and parts of the Laptev Sea among other locations. These data provide tantalizing information about the relative importance of rivers and coasts, but also illustrate potential difficulties in comparing data from disparate sources. Along a portion of the Canadian Beaufort Sea coast (1150 km long), sediment delivery from coastal erosion is about 5.6 Mt a^{-1} (Hill et al, 1991). Sediment delivery from the Alaskan Beaufort Sea coast (344 km) is 4.8 Mt a^{-1} (Reimnitz et al. 1988). The amount of sediment released to the sea from a portion of the Russian Arctic coast (85 km along the Anabar-Olenyok section) is 3.4 Mt a^{-1} (Are 1998, Kassens 1998). Note that the estimated sediment delivery from coastal erosion along the Canadian Beaufort Sea is about 0.006 Mt km^{-1}. This is nearly an order of magnitude less than that for the Laptev Sea coast (0.04 Mt km^{-1}) and about half that of the Alaskan Beaufort coast (0.014 Mt km^{-1}. Different techniques were used for the Canadian estimate (subaerial erosion only), which may account for a portion of the discrepancy. Sediment input from rivers draining into the Arctic Ocean is also highly variable and subject to considerable uncertainties. As an example, the Mackenzie River discharges about 127 Mt a^{-1} to its delta, of which approximately half is trapped in the delta (MacDonald et al. 1997). The Lena River discharges from 12 to 21 Mt a^{-1} of sediment, of which only 2.1 to 3.5 Mt may reach the sea (Are 1998). Thus, input from coastal erosion rivals or exceeds river inputs in some areas (Are 1998, Reimnitz et al. 1988).

Estimation and understanding of coastal sediment input and evolution requires compilation of information about environmental forcing and local geological and cryological conditions. Mean annual ground temperatures vary from less than –10°C on land to above zero in the nearshore coastal waters. Subaerial and subsea permafrost degrades rapidly within 10’s of meters of the shoreline and large blocks of frozen ground and saturated, thawed sediments fall into the shallow seas and lagoons at rates as high as 20–30 m or more every year (e.g. Are 1988, Reimnitz et al. 1988, Harper 1990, Dyke and Wolfe 1993, Solomon et al. 1993, Dallimore et a.l 1996, Grigoryev 1996). Ice content within frozen sediments along with the presence of winter ice and associated ice scouring and bulldozing are the primary differences between temperate and high-latitude coastal processes. Rates of coastal erosion and evolution in many parts of the Arctic are rapid by any standard, especially when only the ice-free period during which wave activity is possible is considered. However, ice entrainment processes are thought to be equal or greater in fostering sediment removal and coastal erosion (Reimnitz et al. 1988). Subaerially, interstitial and/or massive ice in sediments influences the high latitude erosion process by providing transient strength to unlithified sediments allowing the development of over-steepened cliffs and under-cut notches (Are 1988, Dallimore et al. 1996). Thermal subsidence of transgressed coastlines may help to drive erosion in some locations (e.g. Shah 1978, Are 1988, Wolfe et al. 1998). Entrainment of sediment in frazil ice and its subsequent transport is known to be very important in a variety of Arctic settings (e.g. Reimnitz and Barnes 1987). However, it should also be noted that along other portions of the Arctic Ocean coasts, especially the High Arctic, the ubiquitous presence of sea-ice locks the land-ocean interface into a more stable form. In still other locations, rising global sea levels cannot keep pace with land still rebounding from depression by ice during the last glaciation. Rapid sea level regression favors the development of saline permafrost as land emerges from the sea into colder subaerial environments and saline pore waters are concentrated to from pockets of unfrozen brine in the newly formed frozen ground. It will be necessary to capture the full range of high-latitude coastal variability in order to build comprehensive databases of sediment delivery.

These differences in rates and processes require standard approaches of observations if we are to develop an accurate and consistent assessment of sediment input to the circum-Arctic shelves and basin.

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Arctic Coastal Dynamics Workshop

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Deltas in the Arctic
H.J. Walker

Seismic Shot Hole Evaluation of Massive Ground Ice in the Richards Island, N.W.T. Area
F. Wright, S.R. Dallimore, and L.D. Dyke

Shoreface Profiles of High-Latitude Coasts

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Coastal evolution is controlled by the interaction between hydrodynamic forcing (waves, currents and water levels), and a combination of shoreface and subaerial coastal material properties and morphology. In this context, the shoreface is of fundamental importance in understanding coastal dynamics. While much has been learned about the morphodynamics of sandy shores in mid-latitude temperate zones, there is still considerable uncertainty concerning the prediction of coastal behaviour. Along high-latitude coasts, our ability to understand coastal and shoreface dynamics is further compromised by a lack of information about the coastline and in particular, the characteristics of the shoreface. We define the shoreface broadly to include the all parts of the seabed affected by waves; this includes the area from the surf zone to the edge of the storm wave base.

Based primarily on data from high energy temperate latitude shelves, the lower shoreface and inner shelves of retreating coasts are covered with a lag gravel (low sedimentation rate areas) or mud over a lag sand (where sedimentation rates are high), whereas the upper shoreface is mostly sand. The shoreface to shelf transition is associated with a break in slope from the steeper shoreface to the more gently sloping inner shelf. However, along some beach profiles the change of inclination is indistinguishable. For instance, the Laptev and East-Siberian seas are extensive and very shallow. Waves rework the floor of these seas everywhere up to several hundred kilometers from the shore. Obviously it is unreasonable to consider erosion of the sea floor at such distances from the coast as coastal erosion. In this situation the notion of shoreface becomes meaningless. However, in order to calculate the volume of sediment supplied to the modern sediment transport system by coastal erosion, it is still necessary to define the boundary between erosion of pre-transgressive sediments (derived from downcutting) and reworking of modern marine materials. Since the volume of sediments supplied from subaqueous erosion of the foreshore and inner shoreface often exceeds that from subaerial erosion, a critical question for sediment budget analysis is how to determine the outer boundary of the shoreface along shallow, high latitude coasts.

Solving this problem involves the compilation of existing data on shoreface profile morphology from representative arctic coasts along with information on profile lithology, oceanographic characteristics and shallow stratigraphy. Much of this information exists in the form of hydrographic charts and previous field studies, although it is necessary to conduct additional field work in some locations. The use of new technologies (e.g. multibeam bathymetry) may improve our understanding of detailed morphological characteristics. Examples of shoreface profile from different arctic seas will be presented and discussed to show diversity of its geometry dependent on oceanographic and geological settings. Also, relations between shoreface morphology and intensity of coastal erosion or accretion will be discussed.

Coastal Geomorphology and Stratigraphy Along the Northwest Coast of Alaska as an Index of Past Coastal Dynamics: Speculations for the Future

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The Arctic Coastal Plain of Alaska is primarily composed of unconsolidated marine sequences representing at least six high sea stands dating back into the warm middle Pliocene (Brigham-Grette and Carter, 1992). The superposed sediment packages each consist of a shoreface erosional surface overlain by inner-shelf facies grading upwards into regressive facies. Recurrent transgressions commonly removed the regressive portions of the sequence leaving in many areas stacks of inner-shelf marine sediments subdivided only by disconformities. Across large portions of the coastal plain these marine sequences are overlain by eolian dunes composed of ice-rich sand and distal silt crosscut by Holocene thermokarst lake facies and *in situ* peats. Paleo-shorelines at altitudes of 10 m, 23 m, and 33 m, each delineating the maximum extent of coastal retreat associated with transgression, are discontinuously preserved across the otherwise flat landscape as subtle wave cut scarps, gravel spit complexes, and barrier island/lagoonal facies.

The repeated accumulation of inner shelf sediments, especially across the coastal plain west of Barrow during periods of higher sea level, is a physical statement of conditions set in contrast to the shelf erosion associated with post-glacial sea level rise. With the exception of local areas of sediment focusing, little if any sediment is accumulating on large parts of the shelf today. Reimnitz and others (1988) have shown that coastal retreat along most of the arctic shore is contributing 7 times more sediment to the shelf than are the rivers, yet this sediment is not being stored on the modern shelf; rather it is lost to continental slope.

At least four of the six high sea level events to have occurred along the arctic coast over the last few million years have been associated with conditions warmer than now when the perennial sea ice was dramatically reduced in seasonal extent or eliminated entirely. For example, during the peak of the last interglaciation (Pelukian, MIS 5e), the winter sea ice limit through Bering Strait occurred 800 km further north than it does now and limited evidence suggests that the entire Arctic Ocean may have been nearly ice free during summers (Brigham-Grette and Hopkins, 1995). Lozhkin and Anderson (1995) have shown that boreal forest completely replaced tundra throughout Chukotka at this same time. The entire Bering Sea was certainly ice-free the year around indicating that permafrost may have been completely degraded along the western coast of Alaska. A longer open water season probably enhanced coastal erosion; while at the same time, the regional active layer likely deepened making more sediment available to erosion by streams and rivers. One might speculate that the volume of coarse landforms (bay barriers, beach spits, and barrier islands) is weakly proportional to warmer summers and the duration and persistence of open water during previous interglacials.

The modern thinning of the arctic pack ice (McPhee, 1998) associated with the warmest years in a millennium (Mann and others, 1999) may be an indication that we are about to experience rapid retreat of seasonal sea ice limits in coming decades. Longer open water seasons, like those associated with the last interglacial when arctic conditions were only a few degrees warmer than now, can only result in increased coastal erosion, thickening of the active layer, and an associated increase is sediment supply to the arctic shelves. This will occur regardless of arguments over rates of future sea level rise.

Brigham-Grette and Carter, 1992, Arctic; Brigham-Grette and Hopkins, 1995, Quaternary Research; Lozhkin and Anderson, 1995, Quaternary Research.

Mann and others, 1999, Geophysical Research Letters (March); McPhee, 1998; Reimnitz and others, 1988, USGS Map I -1182G.

U.S. Beaufort Sea Coastline Changes: Past Investigations

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Observations of the Beaufort Sea coast date back to Leffingwell's classic studies in early 1900s. MacCarthy utilized benchmarks to measure coastal morphology, erosion, and barrier island stability around Barrow in the 1940s. Using 1948 and 1964 aerial photography, Lewellen measured erosion rates from Point Barrow eastward approximately 30 km to Dease Inlet. By comparing 1951 and 1983 navigation charts, Reimnitz et al. and Barnes et al. illustrated in a series of strip maps (1:82,000) the changes in coastal erosion and accretion and other attributes for a distance of over 500 km westward from the Canadian border. They characterized the coast as ocean-facing bluffs, lagoon-facing bluffs and deltas; and computed losses of sediment and ice volumes based on bluff heights and shoreface profiles along 35 individual sectors over a 30-year period. Ice volumes were based on estimates of ice-wedge volume and a composite of excess ice volume vs depth for Barrow sediments. The latter was developed by Brown for the International Hydrological Decade underground-ice volume estimate. The published strip maps and accompanying text illustrate the methods of computation and the magnitude of erosion and accretion Hopkins and Hartz also described coastal attributes in an USGS open file report of the Alaskan Beaufort Sea. Walker and Jorgenson and Shur observed multi-year erosion on the Colville Detla. In order to obtain a 50-year record of change, these earlier Beaufort Sea studies should be updated through the late 1990's using high-resolution satellite imagery or conventional aerial photography. Other workshop posters and presentations provide additional information for these and other ice-dominated, Alaskan coasts.

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Arctic Coastal Dynamics in the Areas with Massive Ground Ice Occurrence

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Developing a general classification system for coastal mapping in the Arctic to estimate coastline sensitivity to change and erosion potential. The field work carried out by the ECI group in the coastal areas of the Kara Sea shows that morphological features of the coasts depend on the massive ground ice types. Occurrence of massive (tabular) ground ice causes formation of thermocirques, otherwise, a practically linear shoreline is observed. Areas containing tabular ground ice border the Kara, and in part the Barents Seas, western Laptev and East Siberian Seas in the Russian Arctic. While studying the retreat of linear shoreline requires only measurements along specially established profiles (one-dimensional retreat), thermocirque-like shores need measurements of the retreat area (two-dimensional retreat) or even the retreat volume (three-dimensional retreat), due to complicated "digging-bucket" shape of the hollows. More detailed classification should involve soil types and ice content within the two major groups of coasts.

Technical aspects of coastal mapping and erosion measurements in the Arctic. Estimation of erosion rates. Study of massive-ice coasts with thermocirques was undertaken during 1999 summer by ECI using the most easily available instrumentation. Several leveling profiles hollows were obtained through GPS positioned surveys. Comparison of aerial images (scale 1:60,000 taken in 1947—see below) with GPS positioned mapping allowed us to obtain linear rate of coastal retreat in one of thermocirques on the order of 150 m (3 m per year). Areal and volumetric results were even more impressive. After several key sites are studied and main regularities obtained, it appeared possible to formulate indicators of various coast types and to interpret satellite and aerial images. The latter should be laid as a base for mapping the coastal retreat, as shown by field interpretations of 1:60 000 scale images. VNIIOkeangeologia carries out annual fieldwork in near-shore, shallow water areas of the Russian Arctic. This work is funded by the Russian Ministry of Natural Resources and consists of geophysical (side-scan sonar and seismic profiling) and geological (core and grab sampling) studies. One of the main goals of this work, and which could be used for the project proposed, is to determine migration pathways and pattern of the sediments in the coastal zones of the Russian Arctic. These investigations can be extended to on-shore areas in order to unify observations from both sides along the shoreline in the key sites.

In addition to current fieldwork we propose to use the results of geological survey and mapping of the coastal areas which have been already done during last 30 years. Another suggestion is related to processing of both aerial and satellite images for mapping of the coastal areas of the Russian Arctic. VNIIKAM and VNIIOkeangeologia could provide more than 1000 aerial images ranging from 1:3,000 to 1:60,000 scale taken as early as the1940s–1970s almost for the entire coastal zone. We also have digital satellite images for areas 60 × 60 km with a resolution of 10 m which could be deciphered by means of special software and compared with land-based observations. Using algorithm based on the above mentioned study of Kara Sea, coastal erosion maps at a scale no less than 1:10,000 can be compiled.

The geochemical aspect is of great importance for analysis of coastal dynamics. Once the composition of the sediments, including those trapped in ground ice, is studied and the rate of coastal retreat is estimated, it will appear possible to calculate the mass balance on shore and amount of substance discharge into the ocean. Initial analyses were undertaken (ECI sampling and VNIIOkeangeologia laboratory testing) and showed that some coastal areas with massive ground ice can supply the ocean water with a great amount of soluble and suspended substances probably comparable to those transported by rivers. Developed were special techniques of sampling and testing for macro- and trace elements in frozen deposits and ground ice.

Our experience in examination of massive (tabular) ice and frozen deposit analyses based on the sampling of Kara Sea coast allows determining the following:

- greenhouse gases - CH_4, CO_2 and NO_2—input balance in the process of coastal thermo-erosion;
- gases and low-valence metals (mainly iron), their oxidation in the course of release from permafrost requires consumption of oxygen from both the atmosphere and the hydrosphere resulting in changes of oxygen balance and enhancing anoxic processes in the Arctic air basin.
- composition of gases in fossil ice, especially freons causing ozone-destroying effect;
- organic matter in sediments of the coastal zone to obtain balance estimation of organic carbon mass repeatedly entrained into the global carbon cycle in the course of coastal erosion to trace paths and subsequent transformations accompanying immobilization, transport and deposition of sedimentary material.

The studies presented were partly supported by INTAS, Grant #97-0484.

The Organic Carbon Isotope Composition of Amerasian Arctic Continental Shelf Sediments

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A recent synthesis of published and unpublished carbon isotope data of the organic fraction of Bering, Chukchi, and East Siberian Sea continental shelf sediments indicates that carbon isotopes, probably in conjunction with other tracers, could help resolve the importance of contributions of terrestrially-derived organic carbon in Arctic marine systems. One complexity however, is that the stable carbon isotope composition of the organic fraction of surface sediments on the Bering and Chukchi shelf also appears to reflect water column organic carbon incorporation processes that vary in relation to high biological production in the water column. Less negative δ13°C values are observed in sediments that receive proportionally more deposition from higher pelagic production. Terrestrial contributions appear to be most important in areas of relatively low biological productivity in the East Siberian and Chukchi Seas, and in the vicinity of riverine runoff (Fig. 1), although in portions of the Russian Chukchi and East Siberian Seas, terrestrial contributions from eroding shorelines may also be important. These indications are supported by relatively high carbon/nitrogen ratios of organic carbon and higher than expected inventories of bomb fallout Cs-137 in some near-shore areas of the Chukchi and East Siberian Seas.

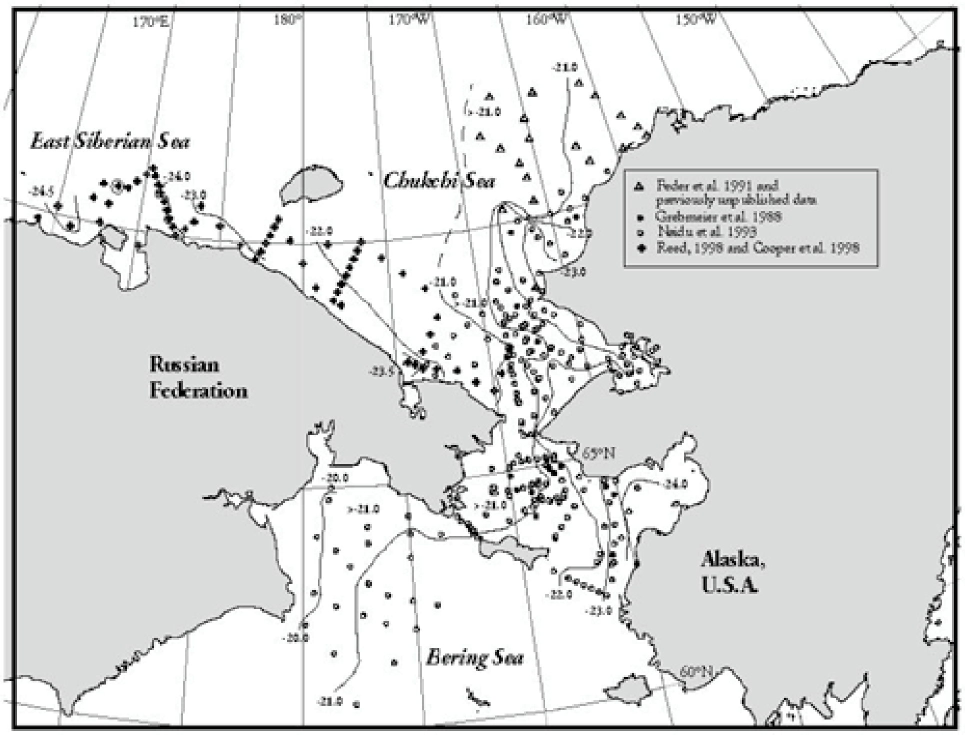

Figure 1. Stable carbon isotope distributions (δ13°C V-PDB) of organic carbon in sediments of the Bering, Chukchi, and East Siberian Seas. Less negative δ13°C V-PDB values are observed in areas of the Bering Sea Data are from Grebmeier et al. 1988, Mar. Ecol. Prog. Ser. 48: 57-67; Feder et al. 1991, IMS Tech Report 92-2, Univ. Alaska; Naidu et al. 1993, Cont. Shelf Res.13: 669-691; Cooper et al. 1998; Chem. Ecol. 15:27-46, and Reed, 1998, M.S. Thesis, Univ. Tennessee, and unpublished data with high production(e.g. Gulf of Anadyr). Elsewhere, terrestrial contributions appear to be important, such as north of Kolyuchin Bay, Chukotka, and the Yukon and Kolyma River deltas where δ13°C V-PDB values decline to less than –23‰.

Applications of Remote Sensing to Arctic Coastal Monitoring and Mapping

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The coastlines of Arctic shelf seas are subjected to the combined effects of a number of dynamic processes, including several that are almost exclusively confined to the polar regions such as thermal suberosion of terrestrial and submarine permafrost and the diverse manifestations of ice action. Studies of arctic coastal dynamics have been restricted by the remoteness and inaccessibility of long stretches of the shoreline and the scarcity of historical data to assess variability, e.g. in coastal retreat, on decadal to centennial time scales. In this context, satellite remote sensing can be of great value in the study of coastal dynamics, both for topographic and thematic mapping purposes (including the delimiting of dynamic regimes) as well as for the direct derivation of quantitative information such as rates of coastal retreat or thermal subrosion. This presentation aims to provide a brief overview of the principles and advantages or drawbacks of hyperspectral and radar remote sensing as applied to arctic coastal dynamics. The importance of concurrent field work for the acquisition of ground-truth data and the establishment of ground control points will be stressed (with cross-references to other presentations at the workshop). The discussion of specific data sets will include surveillance satellite imagery from the 1960's and their utility for benchmarking purposes as well as current synthetic aperture radar (SAR) applications. The examples are based on past and ongoing research in the Laptev Sea (Lena Delta, New Siberian Islands), devoted in particular to the role of sea ice in coastal dynamics.

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Changes in Eurasian Shelf Geometry in the Past 20,000 Years and Their Potential Effects on Arctic Water Mass Exchange

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The continental shelves and channels of the Arctic are critical conduits for water mass exchange among the Arctic, Pacific and Atlantic oceans and Norwegian/Greenland Sea. The geometry of the marginal seas and channels has changed substantially over the past 20,000 years and in-turn affected thermohaline circulation and ventilation of the Arctic Ocean.

The vast expanse of the Asian and Alaskan arctic continental shelves remained unglaciated and was exposed during the last glaciation, when global sea level fell by ~120 m. The reduction of arctic continental shelf area at this time shifted the loci of sea ice formation from the shelves to the Arctic Ocean and probably reduced the lateral ventilation of the Arctic Ocean. Subsequent flooding and erosion of these large, exposed and unglaciated areas mostly reflects the postglacial rise in global sea level.

In contrast, the Barents Sea is the only continental shelf in northern Eurasia that sustained a 2+-km thick ice sheet during the last glaciation (Fig. 1). Upon final deglaciation at ca. 10^{14}C ka, the Barents Sea (present mean water depth of 230 m) was deepened by 100 to 200 m due to remnant isostatic compensation. The shelf progressively shallowed during the Holocene, with ~90% of the rebound complete by 6^{14}C ka. The present circulation in the Barents Sea is largely controlled by bathymetry with North Atlantic water confined to depths of >200 m. Thus, the postglacial deepening of the Barents Sea should have increased the trajectory of North Atlantic inflow into the Arctic. Increased North Atlantic input into the Barents Sea ca. 10 to 6^{14}C ka would have compensatory effects on the production and outflux of arctic intermediate water and possibly arctic surface water. Indeed, extralimital mollusks on Svalbard and subpolar foraminifera from Barents Sea marine sediment cores place the increase in North Atlantic input between 10 and 5 ^{14}C ka. Complicating this interpretation, however, is a substantial elevation of summer insolation during this same interval, with insolation values from 11% to 5% above present.

The eastern limit of the Eurasian ice sheet during the last glaciation is not fully resolved. Certainly the Saint Anna Trough sustained a grounded and calving outlet of the Barents Sea ice sheet to >600 m water depth. However, it remains unknown if another smaller ice sheet existed over the northern Kara Sea shelf, fed from ice caps on Svernaya Zemlya and terminating in the Voronin and Saint Anna troughs. However, there is firm evidence for the *absence* of the last ice sheet in the Pechora River lowland and Yamal Peninsula. Available evidence for the Kara Sea region indicates modest, if any, isostatic effects and no major blockage of drainages in northern Siberia. Deglaciation post 10.5 ^{14}C ka heralded significantly warmer temperatures across Eurasia. Treeline migrated100's km north of present limits and permafrost degraded, with a probable net increase in river discharge.

A number of questions remain unresolved with our current understanding of changes in shelf/ocean bathymetry and fresh water input in the Eurasian Arctic:

1. How much did North Atlantic inflow increase into the Barents Sea with an early Holocene isostatic depression of 100–150 m? What was the concomitant response of other Arctic North Atlantic-dominated currents?
2. What were the changes in water mass flux amongst the Arctic, Atlantic and Pacific oceans during the last glaciation when the Eurasian shelf did not largely exist and with closure of the Bering Strait? What was the affect of reduced shelf area on sea ice formation?
3. When arctic shelf seas formed 9 to 6 ka ago what was the compensatory response in Atlantic and Pacific water inflow?
4. What is the fate of increased fresh water inputs from Eurasian Rivers and influence on sea ice formation and thermal structure in the Arctic Ocean?

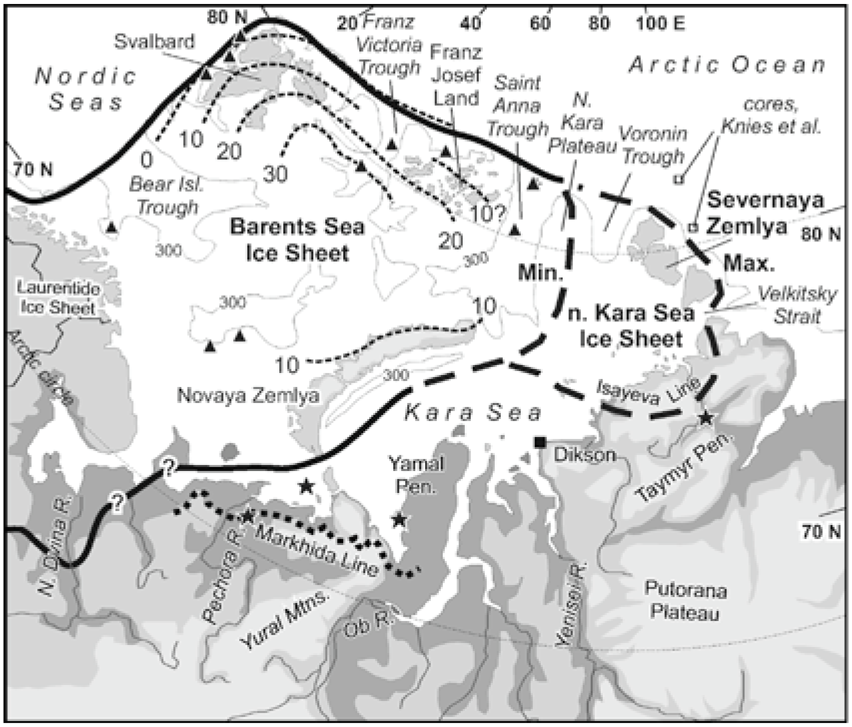

Figure1. Map of the Barents and Kara seas showing inferred LGM ice-sheet limits. Extensive grounding occurred in the Barents Sea. Concentric dashed lines in the northern Barents Sea are emergence isobases in meters asl since 5 ^{14}C ka. Triangles show grounding constrained by AMS ^{14}C ages in marine cores. Much of the southern Kara Sea remained unglaciated. Stars depict ice-free sites. The existence of a northern Kara Sea Ice Sheet remains poorly tested. For a maximum Kara model, we tentatively use the Isayeva Line and infer glacier ice to the northern shelf edge. In contrast, our minimum Kara model has little ice on the Kara shelf and only a 10–20 km expansion of ice caps on Severnaya Zemlya.

Field Techniques for Measuring and Mapping High-Latitude Coasts

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While many techniques suitable for coastal mapping and change detection at high latitudes are equivalent to those employed on mid- and low-latitude coasts, a number of *special survey challenges* can be identified, including access to remote study sites, operations in ice-infested nearshore waters, sparse geodetic and hydrographic control networks, and requirements for survey control on cold coasts. *Distinctive scientific issues* on high-latitude coasts include coastal permafrost and ground-ice, sea-ice properties and shore-zone interaction, and extreme seasonal process signatures. Standardized monitoring procedures and networks can be established with equivalent protocols at all latitudes, but high-latitude coastal monitoring requires some adjustment to account for the distinctive issues and field-work challenges noted above. Although a minimum set of standard methods and objectives may be suitable for a circumpolar monitoring network in both polar regions, it is unrealistic to specify a standard suite of tools for all sites.

For the purposes of this presentation, *field measurement and mapping requirements for high-latitude coasts* are considered to include the following:

- shore-zone repetitive profiling for change detection;
- nearshore, shoreline, and backshore mapping for change detection and sediment budgets;
- raised shoreline surveys for determining uplift rates and relative sea-level change;
- measuring ground and seabed temperatures and seasonal thaw;
- mapping ground-ice content in the backshore, beach, and subsea nearshore,
- observing nearshore dynamics (including shore ice) in cold and super-cooled waters;
- acquiring data for shore-zone classification and mapping.

Field access at high latitudes is commonly by air (helicopters, fixed-wing aircraft on balloon tires, skis, and floats) with associated requirements for light-weight and compact equipment. Ground transport solutions include all-terrain cycles, snowmobiles, and amphibious vehicles. Nearshore operations can be carried out from air-transportable small boats, float-equipped aircraft, and ice platforms. Satellite-referenced positioning systems such as GPS and GLONASS, with associated high-resolution survey hardware and software equipment, provide a means to overcome the lack of geodetic and tidal control at high latitudes. Installation of precision survey control, where required in permafrost terrain, calls for special techniques such as anti-heave benchmark arrays. Survey instruments range from simple lightweight graduated rods and tape, survey altimeters, and conventional optical survey instruments, to standard electronic total stations, real-time kinematic [RTK] differential GPS equipment, and integrated code-phase GPS and optoelectronic total stations. Integration of ground surveys with target-marked aerial photography or other imagery, as well as historical air photographs, enables determination of coastal change with varying precision depending on image resolution. Automated video monitoring systems provide a means of remote shoreline and nearshore observation. Nearshore seabed surveys can be carried out from small boats using compact sidescan sonar and subbottom profilers and can operate in coastal leads where necessary. Compact multibeam sonars are also now on the market. Ground and seabed temperature and thaw measurements can now be made with compact inexpensive packages. Simple techniques can be used for measuring active layer thickness in beaches, but determining depth to ice-bonded sediments in the nearshore remains challenging. Data acquisition for coastal classification can be facilitated by various airborne video techniques.

Computer Techniques for Measurement of Coastal Retreat in the Russian Arctic

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The coastal zone of the Laptev Sea is a representative area for measuring arctic shoreline retreat rates and coastal accumulation (accretion) processes. The length of the continental Laptev Sea shoreline is over 4,900 km. About one third of the shoreline (1,600 km) consist of an Ice Complex, i.e. ice-rich deposits containing massive ice bodies which are subject to active marine erosion. Such areas were studied most thoroughly.

Eroding shores produce a large volume of mineral material incoming to the sea. The amount of such material may be estimated using the following methods:

1) field measurement of the present shoreline and cliff morphometry,

2) comparison of shorelines and cliff tops on different-time topographic maps, satellite images, and aerial photographs. This method allows us to define changes in shore morphology and geometry. We used the software ENVI 3.0 (The Environment for Visualizing Images) to compare the maps and aerial photographs of the key sites in the central and eastern portions of the Laptev Sea coast. ENVI 3.0 allows us to superpose the scanned images quite precisely by matching a maximum number of key points selected on the compared images.

The different-time aerial photographs (scale 1: 30,000–1:5Forb0,000) overlay most precisely: There is a sufficient number of topographic maps, aerial photographs for the studied sites and a limited number of satellite images. However, remote sensing materials (maps and aerial photographs) are few for the 1990s. Therefore, field measurement of present-day coastal dynamics is necessary in addition to computer comparison of remote sensing data. Changes of the shorelines which took place in the last decades and in summer 1999 were introduced into the computer enhanced images based on the aerial photographs.

Preliminary data are available on the Laptev Sea coastal erosion rate (2-6 m / yr). ENVI 3.0 can estimate an average rate of shoreline retreat and long-term trends of the Laptev Sea shore dynamics more precisely. The software can clearly show those portions of the coast which are subject to erosion or accretion.

In 1999, field studies were conducted at seven key sites which represent eroding, stable and accumulating shorelines. The average coastal erosion rates were found to be approximately 1–7 m/ yr. The preliminary estimates and results of coastal processes analysis by ENVI-software confirm our earlier conclusion that the volume of eroded coastal material incoming to the Laptev Sea is comparable with the sediment discharge of the major rivers.

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The Role of Thermokarst Processes in the Sea–Land Interaction in the Laptev Sea Region

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The results of the Russian–German studies in the program “The Laptev Sea System” & “System of the Laptev Sea 2000”, the analysis of published and individual data, and the mathematical computer modeling have made it possible to estimate the role of thermokarst in the postglacial transgression and in the formation of the Laptev Sea shores.

1. In the Late Cenozoic, the Laptev Sea shelf was not subjected to the covering glaciation but underwent, on the whole, an irregular tectonic subsidence. The shelf was the site of compensative sediment accumulation. This led to the leveling of its surface. The Laptev Sea shelf

was subjected to regressions and transgressions as the result of glacioeustatic oscillations of the World Ocean level (Chappel et al.1995, Fairbanks 1989)

2. During the last regression, the shelf deposits, which were saturated with sea water, froze. Syncryogenic ice-rich deposits of the ‘Ice Complex’ (IC) accumulated on the exposed surface of the shelf. Accumulation of the IC was irregular. It reached the largest thickness up to 60 m and more in the internal part of the shelf in the subsiding tectonic structures. The volumetric average ice content of the IC is 80–95%.

3. Thermokarst lakes started presumably to form on the shelf and in the coastal lowlands approximately 12.8 kyr BP (Boling); and by 11–9.5 kyr BP many lakes and alasses were already formed (Kaplina 1981, Kaplina and Lozhkin 1978) and partially drained. At 11–10 kyr BP, the seashore was at the isobaths of 60–65 m at the distance of some 250–400 km from the modern shoreline. Thus the thermokarst lakes appeared in the middle and internal parts of the shelf earlier than it was flooded by the sea.

4. The bottoms of thermokarst lakes in the negative tectonic structures were below the level of the transgressing sea. Therefore, these lakes were transformed into ‘thermokarst lagoons’. This increased dramatically the indentation of the shoreline and accelerated the rate of thermo-erosion of the shores. At the same time, the lakes and lagoons served as traps for the washed-off deposits. This decreased sharply the entry of sediments to the external part of the shelf and the continental slope, especially later that 7.5 kyr BP. (Bauch et al. 1999).

5. During the period from 7.5 kyr BP until the present time, the seashore advanced in the southern direction by 250–150 km and formed the shallow gulfs of Buor-Kaya and Yansky; there appeared straits between the Novosibirsk islands. This became possible owing to the primary fragmentation of the shelf by the thermokarst lakes transformed into the ‘thermokarst lagoons’ in the negative tectonic structures. It should be emphasized that is was the most recent tectonic structural plan of the Laptev Sea shelf, accumulation of large thickness of the IC ice-rich sediments in the negative structures and the above-described IC degradation that determined the very fast rate of transgression in the Holocene and created the modern macro configuration of the shoreline of the eastern part of the Laptev Sea. This stage of transgression is basically completed.

6. The remnants of thermokarst–lagoon shores exist in the Bykovsky peninsula and eastward of the Yana river delta. Cliffs with the thermoerosion niches were formed in the basement of the most recent tectonic elevations. This is exemplified by many shores of the Novosibirk islands (Romanovskii, 1963). This is explained by the fact that the lower boundary of the IC, the bottoms of lakes and the surface of alasses are situated here above the sea level. In the absence of sea currents, these shores are transformed into slopes with baydjarakhs with accumulative shoals formed under them and composed of fine grained sand, silt and loam.

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Coastal Erosion in the Southeast Chukchi Sea: Results from Monitoring and Aerial Photography

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Investigations of coastal dynamics begun in 1987 in the southeast Chukchi Sea included the establishment of an irregularly spaced network of 26 erosion monitoring stations within the boundaries of Bering Land Bridge National Preserve (BELA) and Cape Krusenstern National Monument (CAlaskaR). Analysis of aerial photography acquired between 1950 and 1987 extended the record of observation for a portion of the BELA coast. Shoreline erosion is active along more than 80% of the 250 km surveyed, despite differences in geomorphic setting. Sandy barrier islands and spits with dissipative shoreface profiles comprise about 85% of the BELA coast along northwest Seward Peninsula; gravelly barrier spits and capes with reflective profiles make up about 65% of CAlaskaR beaches. Tundra-backed bluffs dominate the remaining coastline. Transport of sediment along shore toward inner Kotzebue Sound has resulted in the deposition of extensive beach ridge plains at capes Espenberg and Krusenstern during the past 5000 years.

Retreat rates average less than 1.75 m yr^{-1} in both areas, but vary at several temporal and spatial scales. Erosion is localized and depends on the intensity and location of storms passing the coast. Inshore bathymetry, fetch, wind regime, and sea ice and permafrost dynamics also contribute to differences in the vulnerability of coastal reaches to erosion. Storm surge frequency/magnitude diagrams constructed from wind data for the BELA coast suggest that storms that elevate coastal sea level by 1.5–2.0 m will occur every 8 to 10 years. Increases in storm magnitude or storm frequency may be contributing to an apparent increase in the rate of shoreline transgression during historic time. But it is also possible that a slow, steady rise of eustatic sea level since the mid-Holocene triggered a widespread shift from regressive to transgressive sedimentary regimes around the southeast Chukchi Sea about 1000 yr B.P. (J.W. Jordan and O.K. Mason (in press). A 5,000 year record of intertidal peat stratigraphy and sea level from Northwest Alaska.

The erosion monitoring protocol established for these coasts facilitates repeated measurements by park personnel and researchers, and is useful for tracking and predicting shoreline change at specific sites. Measured profiles of the upper shoreface and backbeach acquired at each station will assist in predicting sediment flux and the response of the beach to storms. But point monitoring must be augmented with additional observational and modeling data if we are to understand episodic erosion in the context of longer-term atmospheric, oceanic and terrestrial processes that drive coastal transgression at high latitudes.

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Use of Ecosystem Characteristics to Estimate Surface Elevations and Assess Potential Flooding from Sea Level Rise on the Yukon-Kuskokwim Delta, Alaska

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We evaluated the susceptibility of coastal ecosystems to inundation from predicted sea level rise by surveying ground surface elevations at 550 points along 10 toposequences across coastal ecosystems near Hazen Bay on the Yukon–Kuskokwim (Y–K) Delta in western Alaska. An ecosystem class was assigned to each point and differences in elevations among ecosystems were analyzed within individual toposequences and across the entire 40 × 40-km study area. We identified 8 aquatic and 19 terrestrial ecosystem classes using an ecological land classification approach that hierarchically grouped the physiographic, geomorphic, surface form, and vegetative components of ecosystems. For elevations, a geodetic control network was established using GPS technology to provide a common datum for the field surveys.

Coastal ecosystems had extremely low elevational gradients. Elevations of vegetated ecosystems along the longest toposequence rose only ~1 m over a perpendicular distance of 7.5 km from the coast and saline, and slightly saline meadow types varied < 0.5 m over the first 7 km. At the inland end of some toposequences, elevations showed an abrupt, small (~1 m) rise onto the surface of permafrost plateaus that supported nonsaline lowland ecosystems. When compared among all ecosystems, mean elevations varied remarkably little across the entire study area. As expected, mean elevations were lowest for barren Tidal Guts (0.87 m) and Tidal Flats (1.49 m). Within Delta Active-Floodplain Cover Deposits, where frequent sedimentation prevents organic layer development, mean elevations increased from 1.51 m for Saline Wet Meadow Fringe (*Carex ramenskii*) to 2.01 m for Higher Levee Mesic Willow Scrub (*Salix ovalifolia–Deschampsia caespitosa*). In contrast, within Delta Inactive-Floodplain Cover Deposits, mean elevations varied little and ranged from 1.89 m for Slightly Saline Wet Sedge–Willow Meadows (*C. rariflora–C. ramenskii*) to 2.04 m for Slightly Saline Moist Sedge–Shrub Meadows (*C. rariflora–Empetrum nigrum*), which were two of the most abundant ecosystem types. The mean elevation of the highest ecosystem, Lowland Birch–Ericaceous Shrub Plateau Bog (*Betula nana* and lichens) was distinctly higher (2.86 m) than other ecosystems.

Based on a predicted rise in sea levels of ~0.5 m by 2100 (Warrick et al. 1996), large portions of the coastal margin of the delta could be inundated by water during high tides, and even the highest ecosystems could be affected by storm surges. We speculate that saline ecosystems on active-floodplains probably are in equilibrium with sea level rise and will not change much, although saline meadow types probably will expand onto the tidal flats when the surface becomes higher through sediment accretion. In contrast, slightly saline ecosystems on inactive floodplains receive little sediment and surface accretion is unlikely to keep up with sea level rise, thus Brackish Ponds are likely to expand in the basins behind developing levees. The effects of sea level rise are uncertain for nonsaline lowland ecosystems on the 1-m high permafrost plateaus. Although they are sensitive to salt damage, jacking up of the surface through permafrost formation may exceed the rate of sea level rise and prevent inundation.

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An Integrated Terrain Unit Approach to Analyzing Landscape Change on the Colville Delta, Northern Alaska, USA

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Rates of landscape change on the Colville River Delta were analyzed to assess risks of erosion and identify stable areas for development of the Alpine oilfield. To analyze the rates of landscape change, integrated-terrain-unit (ITU) maps were developed using aerial photography from 1955 and 1992 for three small areas representing areas affected by fluvial erosion and deposition, thaw-lake development, and tidal processes. ITU maps were made for each area for both 1955 and 1992 using codes for geomorphic units (e.g., inactive floodplain cover deposit), surface form (e.g., low density low-centered polygons), and vegetation (e.g.wet sedge-willow tundra). Maps were georectified and the amount of overlap between years was analyzed with a GIS. The various combinations of the ITU's created by the overlay were grouped into six classes (eroded riverbed, other eroded landforms, depositional areas, unchanged riverbed, other unchanged landforms, and unchanged water) that reflect depositional and erosional processes.

During the 37-yr period, only 2.2–2.9% of the three areas had eroded, indicating that the higher floodplain steps (geomorphic units other than riverbed alluvium, thaw lake deposits, and tidal flats) were fairly stable. In contrast, the riverbed was more active; the areas of sandbars that had eroded ranged from 0.4% to 5.4% in different channels. When comparing differences among processes (i.e., fluvial, lacustrine, and marine), the greatest rates of erosion of the higher floodplain steps occurred at the upstream, unprotected ends of narrow islands, where maximal rates of 2 m/yr were measured. Along the sides of islands and cutbanks in meandering distributaries, maximal erosion rates of 1–2 m/yr occurred. Maximal erosion rates were similar along the shorelines of large thaw lakes, where maximal rates were as high as 2 m/yr, although erosion along most of the shoreline was much lower. Changes in the tidal flats were marked by rapid expansion of the tidal flats (up to 6.7 m/yr), particularly at the channel mouths.

The erosion along thaw lakes demonstrates the importance of ground ice in landscape change. Thermal and mechanical erosion of ice-rich sediments by the thaw-lake process provides a central paradox regarding the stability of landforms in the delta: the oldest, highest landforms have accumulated such high ice contents that they become the most unstable areas. During evolution of the deltaic landscape, mean volumes of segregated ice (excluding ice wedges) in the top 2–3 m increases from riverbed deposits (42%), to inactive-floodplains (60%), inactive floodplains (72%), and abandoned floodplains (79%).

Overall, the rates of change roughly agree with the age of the landscape obtained by radiocarbon dating. Based on an average erosional change of 2.4% over 37 yr (0.065%/yr), the delta would be reworked by channel migration in 1500 yr. This rate compares favorably with the radiocarbon dates from the bases of the highest floodplains (2080–2950 yr). Although the rates of change are fairly rapid in geologic terms, the analysis revealed that for engineering design large portions of the area are sufficiently stable for oil development. The maps can be used to situate facilities away from locations that are eroding rapidly to ensure that facilities would not be endangered within hundreds of years.

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Assessment of Contemporary Arctic River Runoff Based on Observational Discharge Records

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The flux of freshwater from the arctic watershed to the Arctic Ocean and hence to the North Atlantic is an essential link in the salt and freshwater balances of the Global Ocean. We have assembled R-ArcticNET, a database of river discharge covering the entire pan-Arctic drainage system, to assess the contemporary climatic mean water balance and to study regional trends in runoff over the past 40 years. The database represents over 3500 gauges in Eurasia and North America and covers a period from the late 1800's to 1990. Most gauges operated between 1960 to present. There is a decline in the number of gauges after 1985 as a result of gauge closings.

Preliminary analyses suggest that trends from the rivers overall are not large and that different regions behave asynchronously. Large parts of southern Canada have experienced reduced runoff and some portions of Siberia show that winter runoff is increasing. Anthropogenic diversions of river waters appear to be a minor factor at present. We are currently using the assembled data to test a permafrost-based water balance model and a river routing model which will be used for predictions of freshwater fluxes in paleo-reconstructions and in future climate change scenarios.

Estimating Ground Ice Volumes in Terrestrial and Marine Permafrost Sequences

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The ice content of perennially frozen terrestrial and marine sediment is a critical factor controlling the rate and extent of processes of erosion and thermokarsting, and thus the response of coastal zones to climate change. The volume of ground ice in nearshore and coastal sediments is known in only a general sense and therefore, its role in subaerial and submarine erosion is difficult to estimate. The distribution and volume of ice are a function of multiple geological and environmental variables, including grain size distribution, sedimentary history and subsurface stratigraphy, former environment of deposition, landform/terrain unit, and climatic trends. These factors result in spatial variations in ice volumes, as well as vertical variations that reflect their thermal history (permafrost aggradation and degradation).

Techniques to determine ground ice volume are not standardized. Ice volume of a vertical sequence can be measured by undisturbed core sampling of the frozen terrestrial sediments, and then related to detailed analysis of the stratigraphy. However, data from drill holes represent only a single location; the spatial variability in ice volume can only be estimated efficiently using geophysical techniques and geological knowledge of the sedimentary sequences and landforms.

Ground penetrating radar (GPR) using antenna frequencies of 30 to 400 MHz can define the stratigraphy within near-surface sediments, locate large bodies of ground ice such as sills, wedges, and other massive forms, and identify the top and bottom of permafrost, all to depths within about 50 meters. Massive deposits give strong radar reflections because the dielectric permittivity of ice (3.2) is appreciably different from that of the surrounding soil or permafrost matrix (5–6). Where clear reflections may not be present because of rough interfaces, diffractions are usually present instead. The slopes of these diffractions (echo time delay vs. profile distance on a radar record) can then be measured to give the permittivity of the overburden above the diffraction. GPR bandwidths centered between 100–400 MHz are optimal for achieving resolution to 30-m depth, with current research suggesting ice detection can be accomplished to 100-m depth with 30 MHz antennas.

An alternate method is to use electromagnetic induction, which senses ground resistivity to a depth of about 6–10 m at a frequency of about 10 kHz using current commercial instrumentation. Resistivity values greater than about 5000–10,000 ohm-m generally indicate massive ice in perennially frozen deposits of silt. In frozen sands and gravels, such values may be typical of the frozen sediment matrix, so that values much greater than 10,000 ohm-m are usually sought to indicate ground ice. A rarely used method is nuclear absorption or thermal neutron scattering. This method relies on the presence of hydrogen atoms, which of course, is greatest where ice is present. In addition, acoustic sub-bottom profiling or refraction shooting may be used to define submarine stratigraphy and the presence of permafrost, respectively, but its usefulness in locating ground ice has not been determined.

Geophysical, as well as borehole data, must be interpreted using terrain, paleo-terrain, and sedimentary environments and only then, can it be used to define spatial variability in ground ice volume. Data from perennially frozen sequences on the North Slope of Alaska exhibit vertical and lateral changes in ice content that can be related grossly to terrain/landform/sediment assemblages. However, these data indicate that volumetric variations with depth are not consistent from place to place, and only near-surface sediments with similar geological and climatic histories show consistent lateral changes in ice content.

The 11-yr Cycle in 20th Century Storm Surges in the Bering and Chukchi Seas: Implications for Global Change and Impact on Communities

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Spectral analysis of 96 years of Bering Sea storm records reported in the Nome News (1899-1903) and the Nome Nugget (1901–1993) newspapers indicate regularities in the 11-, 5- to 7 and 3-year periods. Statistical tests on the 11-year period found no statistically significant correlation with sunspot cyclicity despite a tendency toward maximum storminess during low sunspot periods. Possibly, anthropogenic effects have altered natural cycles. The 3- and 5- to 7-year cycles may correlate with variability in the El Nino Southern Oscillation and easterly shifts in the mean position of the North Pacific low pressure anomalies. Storm surges were infrequent from 1916–1928 and 1947–1959, while the most frequent and intense storms hit during 1900–1913, 1936–1946, 1974–1976 and in 1992. Erosion in the Chukchi Sea also co-occurs with maximum storminess. Storm surge hazards are exacerbated by unwise engineering solutions to coastal erosion, as evident from the histories of Nome and Shishmaref.

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Coastal morphology and erosion of the Khatanga Bay

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A total 630 km of coastline was mapped using field studies, including aerial observation, analysis of aerial photographs, and review of previous field surveys. Coastal erosion rates were estimated by comparing 1947–50 and 1970–72 aerial photographs and special cartographic technique. The average annual retreat of cliffs for 450 km along Khatanga Bay was mapped. Calculations for 43 coastal sections were made to estimate wave energy, alongshore sediment transport rates and directions, and on off-shore sediment transport rates. The data employed included water depth, coastline direction, pack-ice offshore limits, wind speed and direction, which was measured in the study area at meteorological stations during 1948–77 open-water seasons.

The Khatanga Bay is a relatively narrow, large tidal estuary extending north-eastwards for 220 km, with an average width of 37 km. As a result there are some particularities in coastal development compared to open sea coast. Wave energy is two times less than in adjacent western part of Laptev Sea (260,000 and 50,000 to 140,000 units, respectively). Alongshore transport sediment transport is more important than on-offshore transport for most of the coastal segments.

The on-off shore sediment transport is considerable in only two localities: in north-western part of the study area which is exposed to waves from the Laptev Sea (82,000–172,000 units) and on the sourthern section of the coastline (80,000–105,000 units). The value of on-off shore sediment transport in the other areas do not exceed 48,000 units. Alongshore sediment transport is directed southwards to the Khatanga River along the southern shores of the bay and Taimyr Peninsula (4,000–10,000 units) The values of alongshore sediment transport are considerably less and the directions vary along eastern coast.

Coastal retreat rates are less than along open sea coasts mainly due to less value of wave energy. Coastal retreat dominates in northern part of the study area of Cape Kosistii-Senka River. Comprised of unconsolidated sediment, windward, low (>25m) retreating coastal cliffs of the Taimyr Peninsula in this segment are being eroded everywhere (max 1.1 m per year).There are no dominant directions of longshore sediment transport along the high (<60–80m) coast of

A Modern Database and Map of Arctic Bathymetry

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The following is presented on behalf of Members of the IOC, IASC, IIHO. The editorial board for the International Bathymetric Chart of the Arctic Ocean (IBCAO) is assembling available bathymetry north of 64∞N for assimilation in a digital database that will provide a reliable description of the depth and morphology of the Arctic seabed. This activity was triggered by recent initatives that have resulted in easier assess to existing data sets: a regional contour map that is based upon the substantial holdings of the Russian Navy has just been published; the U.S. Navy is releasing historic and modern observations collected by submarines operating under ice; data from Swedish and German icebreakers has been released.

Combined with prospects for swath mapping information from the U.S. Navy SCICEX program, these developments have provided an impetus for rationalizing existing data sets and for developing a procedure to assimilate future observations. IBCAO has developed a strategy for mobilizing the human, technical, and knowledge resources of eight nations with research and mapping interests in the study area: Canada, Denmark, Germany, Iceland, Norway, Russia, Sweden, and the U.S.A.

The plan respects regional data sensitivities by allocating to each coastal state the responsibility for assembling proprietary and public domain data within the area adjacent to its own coastline; the three High Seas enclaves within the study area will be treated collectively, using only published or public domain data. Project completion is anticipated in the year 2000, when the digital database and a map will be placed into circulation. This poster illustrates constituent data sets that have so far been assembled for inclusion in the database. It also shows the progress achieved to date through a visual comparison of old and new maps.

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the Hara-Tumus and Urung-Tumus Peninsula due to variable shoreline orientation. Cliff sediments consist mainly of unconsolidated sandy and muddy materials, but there are some localities of sandstone and mudstone cliffs and low tundra cliffs. Coastal erosion rates increase in the zones of strengthening or divergent alongshore sediment transport (to the north of Cape Kosistii). The most rapid annual retreat rate here is 1.8 m per year (maximum in the study area). The western coast of Urung-Tumus Peninsula is being eroded due to low relief and high ice contents (0.6 to 1.1 m per year).

The comparative stability of the southern coast of Khatanga Bay is a result of the deposition of fine material advected into the area by the Khatanga River and material eroded from cliff on the north. The annual coastal erosion does not exceed 0.2 m per year in this area (including Kogevnikov Bay).

Six coastal types for the study area were defined and mapped. Generally, the coastal types vary spatially from erosional to accretional from north to south along the bay.

Length of different coastal types in the Khatanga Bay.

Coastal types	*Western coast (Taimyr Peninsula)*		*Eastern coast*		*Entire bay*	
Length	*km*	*%*	*km*	*%*	*km*	*%*
Erosional	96	45.7	255	60.7	351	55.7
1.with vertical cliff and thermoerosional niche	9	4.3	21	5.0	30	4.8
2. with episodic cliff erosion and presence of thermo-denudational relief	60	28.5	156	37.1	216	34.3
3. with widespread thermo-denudational relief in upper larger cliff sections and low retreating in smaller lower sections	27	12.9	78	18.6	105	16.6
Accretional	114	54.3	165	39.3	279	44.3
1.with low coastal cliff fronted by wide tidal and wind flats, comprised of sands or muddy sands	87	41.4	96	22.9	183	29.0
2.marshlands	—	—	42	10.0	42	6.7
3.deltas	27	12.9	27	6.4	54	8.6

The Coastal Sea Ice Environment Study in the White Sea

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It is well known is that sea ice is an important component of the global climate system controlling natural processes in the polar oceans. However, little is known about the sea-ice impact on the sea floor, the coastline and their habitants, and especially, in the coastal environment with the tidal dynamic. The annual advance and retreat of sea ice may be considered as a major physical determinant of spatial and temporal changes in the structure and function of marine coastal ecosystems.

In this presentation I demonstrate some of data obtained in the tidal zone of Kandalaksha Gulf (White Sea) during the 1996-1999 period. Previous observations in this area were mainly obtained during the ice-free summer season, however, there was no information on the ice -covered winter season (7 months duration), and, especially, on the sea-ice itself. During three expeditions in the winter season there were conducted series of standard transects along of coastline with sea ice samplings including the under ice observations of the sea ice/bottom floor interactions. Interannual cycles or trends in the annual extent of the sea ice during this period of observations have shown significant effects at all levels of the food web from the winter production of the sea ice algae to breeding success among seabirds in the summer. It was concluded, that to understand all spectra of the ecological problems caused by pollution on the coastal zone, as well as, the problems of the sea ice melting caused by global warming, requires an urgent integrated long-term study of the physical, chemical, and biological processes occurring in the coastal-shelf zone in the Russian Arctic.

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Challenges of Managing an Ambulatory Boundary: The Coastline of the Arctic National Wildlife Refuge, Alaska

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The Arctic National Wildlife Refuge (NWR) encompasses more than 19 million acres of arctic and subarctic habitats in northeastern Alaska, bounded by the Beaufort Sea to the north. The coastal boundary of the Arctic NWR was defined as following the line of *extreme low water* of the Arctic Ocean between the Alaska-Canada International Boundary and the west bank of the Canning River, including all offshore bars, reefs, and islands and associated lagoons. In 1997, the United States Supreme Court affirmed in United States v. Alaska, No. 84 Original, that the Arctic NWR's coastal boundary is naturally ambulatory and therefore migrates as a result of changes in relevant physical features. The use of this particular tidal boundary is unique among refuges in the National Wildlife Refuge System, and poses administrative challenges for managing a premier wildlife conservation and wilderness area adjoining state-owned submerged lands that are targeted for oil leasing and development. Potential transboundary issues could include changes in the size and configuration of adjoining lease tracts and private inholdings as the boundary ambulates, as well as disputes over the location of support facilities and access rights. Construction of artificial structures in shallow waters could also affect the physical processes shaping the islands and bars that delineate the boundary, impacting the ecological integrity of the nearshore floral and faunal communities. Additionally, the predicted effects of global climate change could accelerate coastal variability in the eastern Alaska Beaufort Sea, thus further altering the Arctic NWR boundary.

Effective and timely monitoring of the status of relevant coastline features along the Arctic NWR boundary is prudent for adaptive management and dispute resolution processes. The U.S. Fish and Wildlife Service is presently evaluating various field and remote-sensing methodologies to periodically review the boundary's location, as well as to enhance basic knowledge about long-term environmental change in arctic coastal ecosystems. In our poster presentation, we will 1) summarize current information on the nearshore marine ecosystem of the Arctic NWR, 2) discuss problems arising from incompatible data sources and an unknown tidal epoch, and 3) outline the need for an effective coastal monitoring program for the Arctic NWR to address both administrative and environmental objectives.

Effects of Ice and Storm Surges on Delta and Shoreline Processes

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The sediment transport and deposition processes and their geomorphic expressions in the Alaskan Arctic coastal environment have several unique features that are a combined resultant of prolonged ice and episodic storm-surge effects. Eight to 9 months in a year the ice-covered coast is hydrodynamically generally static. At spring break-up as the river ice melts earlier than the offshore ice, there is the unique phenomenon of turbid fluvial overflow and deposition of terrigenous sediments over sea ice. The subsequent dispersal of this ice-borne sediment results in the lack of delta-front platform lithofacies. The ice-free season is also marked by low energy sedimentary regime with the exception during occasional storms which are accompanied by large-scale littoral sediment transport, barrier island deformation, coastal bluff degradation (1–10 m/yr), by accelerated thermoerosion and wind-induced wave reworking of beach and nearshore sediments.

The early phase of the winter freeze-up is generally dominated by sediment entrainment in sea ice, and beach reworking by ice pushed onshore by storm surge. However, the exact process of particle entrapment in ice remains unresolved. The latter winter phase is governed by ice gouging of the nearshore. Attempts to assess the yearly sediment budget for the delta marinefacies and adjacent lagoons poses a challenge because of the lack of reliable method to estimate mass sediment accumulation rates there.

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Weathering of Permafrost Sediment on the Cliffs of Thermal Abrasion

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Permafrost and active layer grounds was studied on the cliffs of thermal abrasion coasts (Kolyma-Indigirka Lowland, the coast of East-Siberia Sea). The cliffs of variable age (0–300 years) were investigated. The field studies included the description of cryogenic textures, measurement of magnetic susceptibility, pH, Eh, distribution of mobile ions. The data show that the young cliffs (active modern thermal abrasion) differ from the ancient cliffs (zero modern thermal abrasion). The time dependence of the stage of transformation of the ground by weathering was found at the cliffs. The intent of the present paper is to discuss a possibility to use this dependence for the determination of the age of cliff and the speed of thermal abrasion.

In the case of linear changes of the transformation of the ground by weathering a current stage of weathering S_{th} on the depth h is:

$$S_{th} = S_{00} + ((H_r - h) / H_r \cdot (S_{T0} - S_{00}) * t / T_R$$

and

$$t = T_R \cdot (H_r / (H_r - h)) \cdot (S_{th} - S_{00}) / (S_{tr} - S_{00})$$

where T = age of surface of cliff (years)
T_R = relaxation time of the weathering profile (years)
H_r = stationary thickness of the weathering layer (m
h = istance from surface of cliff (m)
S_{00} = stage of weathering of sediment at the surface of cliff for start of weathering.

S_{00} is equal stationary S inside of permafrost massive.

If time changes, the thermal denudation is linear, and the speed of thermal denudation V (m per year) is:

$$V = h / t.$$

Magnetic susceptibility was used as a parameter to determine the weathering stage of sediment in the following example. The magnetic susceptibility of ground changes during oxidation of magnetic minerals in the weathering layer. In this case the current stage of weathering is:

$$S_{th} = (\eta_{th} - \eta_{0}) / \eta_{00},$$

and

$$S_{TR} = (\eta_{TR} - \eta_{00}) / \eta_{00},$$

where η is magnetic susceptibility of ground.

The speed of thermal denudation was calculated according to these technique for the key set at the coast of East Siberia Sea (0.75 m per year). A similar result (0.68 m per year) was calculated on the base of direct measurements of distance between cliff and stationary point.

This technique make in possible to determine the age of the surface of the cliffs of thermal abrasion and to calculate the speed of thermal denudation at the base of one-time measurement of distribution of stage of weathering. Magnetic susceptibility, dielectric properties, chemical and mineralogical parameters, isotope content of carbon and other properties of ground which changes by weathering may be used to determine the weathering stage. The phenomenon of weathering of permafrost sediments in the aeration layer will be studied as a base of this technique in planned projects.

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The Zhokhov Site, Siberian Arctic

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The Zhokhov site, excavated in two field seaso`ns (1989-90), is located far north on the small arctic island of the same name (Pitul'ko 1993, Pitul'ko and Giria 1994, Pitul'ko and Kasparov 1996). Zhokhov Island is situated below 76°N latitude and belongs to the New Siberian island chain, which constitutes the natural boundary between the Laptev and the East Siberian Seas.

Abundant artifacts and faunal remains characterizing ancient aboriginal culture were discovered, including numerous microprismatic cores and microblades, pieces of hunting equipment (both "regular" bone/antler artifacts and composite tools with flint insets), and wooden artifacts. Among the latter a sledge runner fragment is included. The dating of the site is based on a series of carbon dates (21 samples) obtained in three different laboratories.

Bone, wood, and charcoal specimens were dated. The dates have a good correlation, and, what is very important, there are close correlations between dates obtained from organics of different nature (bone, wood)—7,810 ±180 (fragmented bones, LE 3534); 7,870 ±60 (wood, LU 2432); 7,930 ±40 (fragmented bones, GIN 6400). The mid-value varies from 7,800 to 8,000 BP (non-calibrated age meanings). A single charcoal sample (LE 3527) is 8,563 ±180 BP. The underlying stratum is dated to 8,790 ± (LU 2502) and defines the terminus post quem for this site. Calendar age of the site ranges from 8480 to 8175 BP if calculated with 1 sigma. During this time, the shoreline was very close to the site, and the island was probably NOT an island 8000 yrs ago.

The significance of the site for the coastal erosion/permarfrost studies is that the site as well as the bone remains of terrestrial animals such as mammoth (the northernmost dated one is known from the Bennette island, DeLong islands; the age is approximately 13000 BP) provides a firm background to evaluate *terminus post quem* for the western part of the arctic plain which had been transgressed/eroded in the Terminal Pleistocene and Holocene. The biggest islands of the New Siberian group were possibly connected with the mainland even 3000 to 3500 years ago.

The site provides also an important data for the permafrost studies. Three generations of the Holocene ice veins were found during the excavations as well as the evidence of two late Holocene thermokarst cycles (the oldest one is dated to 2200 yrs BP, the second one is very recent, or modern).

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Ground ice conditions along the Beaufort Sea coast, Northern Yukon

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The combination of glacial history, stratigraphy and cold climate has contributed to the ice-rich character of the Mackenzie Delta–Yukon coastal plain area of the western Canadian Arctic. Evidence of massive ice is widespread, however the most spectacular exposures occur in coastal sections where wave action removes slumped debris. The combined result of thermokarst and coastal erosion produces extremely high rates of coastal retreat. This paper combines the results of two projects: first, an investigation of massive ice bodies in the Yukon coastal plain and second, a ground ice mapping project. The latter involves the use of morphological methods to approximate ground ice volume at several sites along the Beaufort Sea coast. Employing published maps and aerial photographs, we distinguish various terrain units on the basis of surficial material, genetic category, morphology, and visible landforms. Supplementing this information with field data, we estimate the volumes of different ground ice types and the percentage of ice content for each ice type. We then calculate a total ground ice volume for each terrain unit. The method was developed so that results could be readily updated with additional information and could be easily input into a geographical information system for widespread mapping of ground ice.

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Understanding Climatic Controls on Coastal Dynamics and Rate of Land-Shelf and Shelf-Basin Interactions

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The primary goal of this presentation is to demonstrate dependence of land-ocean processes and coastal dynamics in the Arctic of climate variability. We build our analysis on the results of (Proshutinsky, A. Yu., and M. A. Johnson. Two circulation regimes of the wind-driven Arctic Ocean. Geophys. Res. 102, 12493–12514, 1997). They have shown that wind-driven ice motion and upper ocean circulation alternate between anticyclonic and cyclonic states. Shifts between regimes occur at 5- to 7-year intervals, resulting in a 10- to 15-year period. The anticyclonic circulation regime (ACCR) has been observed in the model results for 1946–1952, 1958–1962, 1972–1979, and 1984–1988. The cyclonic circulation regime (CCR) prevailed during 1953–1957, 1963–1971, 1980–1983, and 1989–1997. The regime shifts are fundamentally important to understanding the Arctic’s general circulation and particularly for estimating pollution transport and the rate of land-ocean interactions and coastal dynamics. It is important to understand which circulation regime prevails. Preliminary results reveal significant differences among atmosphere, ice, and ocean processes during the anticyclonic and cyclonic regimes in the Arctic Ocean and its marginal seas.

Based on existing data and results of numerical experiments, we conclude that during the anticyclonic circulation regime the prevailing processes lead to increases in atmospheric pressure in the Arctic, in ice concentration and ice thickness, river runoff, and surface water salinity—as well as to decreases in air temperature, wind speed, number of storms, precipitation, permafrost temperatures, coastal sea level, and surface water temperature. As a result of the dynamic-thermodynamics processes we expect that the rate of land-shelf and shelf-basin interactions (transport of ice, fresh water, sediments, pollutants) is lower than usual during the anticyclonic circulation regime.

During the cyclonic circulation regime the prevailing processes lead to increased air and water temperatures, wind speed, number of storms, open water period, and heights of wind waves, and to decreases in ice thickness and ice concentration, river runoff, atmospheric pressure, and water salinity. These processes enhance the magnitude and rate of land-shelf and shelf-basin interactions. Cross-shelf transport of sediments and contaminants is promoted and sediments and contaminants are flushed out of the coastal regions and shelves.

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Russian-German Cooperation SYSTEM LAPTEV SEA 2000: The Expedition LENA 99

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In this poster we present a summary of the Expedition LENA 99, which was carried out within the framework of the Russian-German cooperation SYSTEM LAPTEV SEA 2000. From the end of April to the middle of September 1999 a total number of 42 Russian and German scientists, divided into 8 teams, focused on modern processes and the environmental history of the Lena Delta, the New Siberian Islands and the Laptev Sea coastal region.

The first group, consisting of teams 1–3 (winter, spring and summer), concentrated on modern processes of permafrost-affected soils, i.e. the budget of methane and carbon dioxide, the influence of microbial communities and the water and energy flux in the active layer. This group had its base at the biological station Samoylov, which is a small island in the central part of the Lena Delta.

Teams 4 and 5 focused on the sedimentary and environmental history of the Lena Delta. Team 4 concentrated on the investigation of deep lakes in the western part of the Lena Delta (Arga Island). During winter sub-bottom profiling was carried out by ground penetrating radar. Permafrost drilling equipment was applied to recover lake sediment cores. Team 5 carried out geomorphological studied in the southwestern part of the Lena Delta (Olenyokskaya Channel). Ice-complexes in this region were sampled for dating and sedimentological investigations.

Team 6 was based on the small RV Dunay. Several key locations along the Laptev Sea coast were studied in regard of coastal erosion. Geodetic measurements of the coast lines were carried out, detailed shoreface profiles were obtained by echosounding, and shallow seismic was applied to identify sub-sea sedimentary and permafrost structures.

Teams 7 and 8 concentrated on paleoclimatic and paleoenvironmental reconstructions based on multi-disciplinary investigations of selected permafrost profiles. Geocryological field studies of natural exposures and detailed sampling of permafrost sections for laboratory work were performed on the New Siberian Islands (Bolshoy Lakhovsky) and in the Eastern part of the Lena Delta (Bykovsky Peninsula).

The Importance of Sea Ice for Arctic Coastal Dynamics

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Arctic coastal retreat rates typically are 2–6 m/yr, very high when compared to open-water coasts when we consider that inner shelves and shores here are ice-covered 9 mo/yr. A video shows various sea ice actions in the arctic coastal zone, ranging from river-flooding of fast ice, ice gouging and wallowing, sediment entrainment into pressure ridges with transport onto shore, to the action of frazil ice in supercooled water. Sea ice protects and armors the coast during winter. But in open water, ice modifies the coast in many ways, with a main role being in entrainment and transport of sediments from the coastal zone to the deep sea. Sea ice therefore is both a passive and an active agent.

As passive agent, fast ice protects shore face and coast from the erosive and modifying marine energy. But it also strongly influences the manner in which river water with sediments enters the sea during the short period of break up and peak discharge of Arctic streams. The presence of fast ice causes river water to spread over the ice, allowing water to cascade through openings with swirling motion eroding craters with 50 m diameter and 7 m depth below delta surfaces. Large amounts of frazil ice are formed at the turbulent interface between fresh and salt water, removing the erosion products from developing strudel-scour craters.

As active agent, sea ice plows the shelf surface producing gouges as deep as 5 m with flanking ridges also several meters high. In the process, sediment is bulldozed in the direction of ice drift, generally parallel to the coast and local isobaths. In a seaway, ice in bottom-contact wallows, giving the shoreface and beaches the characteristic ice-wallow relief, in the process re-suspending bottom sediments. This process therefore also results in suspended sediment transport by currents. As a sedimentologically active agent, ice compressed where in bottom contact incorporates sediment into pressure ridges. When such ice encroaches onto land, the incorporated sediment upon melting produces hummocky relief on beaches and barrier islands. This shoreface derived material nourishes and elevates beaches, while intermittent overtopping by storm surges smoothes and winnows out the fines, leaving behind sandy gravel. Under proper conditions, ice encroachment elevates beaches above storm-surge level, making them habitable for birds and natives. Coastal retreat requires shore-face deepening, or else the retreat would stop. Sediment entrainment through the action of frazil and anchor ice in supercooled water (suspension freezing) is the process enabling cross-shelf transport from shore to deep water and thereby drives coastal retreat.

Considering the entire Arctic Ocean, the intensity and effectiveness of the various processes considered vary, along with the form and behavior of the coastal zone. Accepting suspension freezing as principal agent driving coastal retreat, sectors bordered by shore polynyas would be most dynamic at the present stage in the cycle of glaciations. Erosion products from these sectors would also yield the largest amounts of sediment to the Arctic Ocean.

On Biogeochemical Consequences of Coastal Erosion in the Arctic Seas

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Any attempt to understand the effect of the Arctic Ocean on global change or the effects of global change on the Arctic Ocean requires thorough knowledge of the coastal processes as a linkage between land and ocean processes in the Arctic. The coastal zone plays an important role in the Arctic land-shelf-basin system, because the major transport of fresh water and solid material into the Arctic Ocean is determined by 1) the riverine discharges from Eurasia and North America and 2) coastal erosion.

There is a lack of data for the biogeochemical signal of coastal erosion onto the Arctic shelf. This process is considered only from geomorphological point of view (Are 1985, 1998, 1999; M. Grigoriev, personal communication), in the permafrost research group dynamics of the coastal line is now underway. An intensive research for the Lena River–Laptev Sea system as the most sensitive element of the arctic environment was done in frame of the Russian and French Project “SPASIBA,” the Russian and German Project “LAPEX,” “Laptev Sea system,” and “Ecology of the Marginal Seas of the Eurasian Arctic (Kassens et al., eds., 1999). It was assumed that the main modern process controlling organic carbon deposition of dominantly is from terrigenous organic matter (OM) supplied by the rivers (Stein et al. 1999). Likewise, the transport of organics due to the coastal erosion and their influence on coastal biogeochemistry was not investigated. Transformation of terrestrial organic carbon, dynamics of the CO_2-system and dissolved CH_4, and isotopic terrestrial signal at different trophic levels was also not investigated in the coastal zone.

Our ongoing research (1997–99) was initiated with findings of anomalous high values of pCO_2 in the surface coastal layer in the East-Siberian and Chukchi Seas (1994). Previous data indicate that the arctic rivers are supersaturated 2–3 folds by CO_2 in regards to the atmosphere, whereas only restricted areas adjacent the river’s mouths are supersaturated by CO_2 (Semiletov et al. 1996). High positive CO_2 gradient (more than 1000 atm) between the surface waters and air in sites removed from the riverine influence indicates the existence of non-riverine source of CO_2 into the coastal waters (Semiletov 1999). This increase of the surface pCO_2 is correlated with increase in the depth of permafrost and ground ice volume. It would be possible that the increasing in pCO_2 values might be related to increase in the coastal erosion induced by thermokarst and hydrodynamics, because permafrost with the higher ice-content is impacted faster by thermokarst processes (induced by global warming). It correlates well with C^{13} (in sediment C org) data obtained in the different arctic seas (L. Cooper and S. Naidu 1999, personal comm.); the most terrestrial (light) C^{13} values were found in the Laptev and East-Siberian Seas.

Present data indicate that rate of coastal erosion in the Arctic might be changed from a few meters up to tens meters. Our data (1997) indicate a strong terrestrial signal in distribution of 13C org in the coastal surface sediment in the eastern part of the Laptev sea. Laptev Strait data agrees with the anomalous high pCO_2 values in the bottom water (up to 2000 microatm) near ice-complexes with high rates of the coastal retreatment (1997, 1999). The results (1998) indicate also high organic content (up to 10–12%wt.) and C/N ratio in the coastal sediment remote from the riverine input that is induced probably by the erosion of coastal permafrost with typical C/N ratio about 16 (Semiletov, *Transactions of the Russian Academy of Sciences*,1999, in press). Crude evaluation for transport of coastal OM in solid form onto the shelf (Yakutia) indicates that this value is similar with transport of OM in dissolved form of the Lena River.

End-point of this research would be an evaluation of the role of coastal erosion in regional carbon cycling and input to the food web with nutrients. Influence of organic mineralization on food web might be increased in future because the present greenhouse warming might appear not only in a mean temperature rise, but in increase of atmospheric general circulation, especially in cyclone’s frequency along the coastal line and over the inland Arctic with increased coastal erosion and transport of terrestrial OM onto the shelf. Recent data indicates that atmospheric pressure gradient between centers of the Siberian High and Aleutian Low is increased significantly during the last 30 years and that agrees with increase in the seasonal amplitudes of atmospheric ground temperature and Siberian riverine discharge. Therefore, a positive feedback loop might work between strong efflux of the main greenhouse gases (CO_2, CH_4, N_2O) due to the degradation of permafrost, the drying of soils, the expansion of thaw lakes and change in the atmospheric circulation and land hydrology–shelf environment.

Thermokarst and Erosion as Factors of Oriented Lakes Enlargement

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Fifty years ago Black and Barksdale (1949) described the “oriented lakes” that occupy the northern portion (>70[N]) of the Arctic Coastal Plain, Alaska. Oriented lakes are characterized by having a high length-to-width ratio (up to 5:1 but usually between of 2:1 to 3:1) and have a depth rarely greater than 10 ft (Carson and Hussey 1962). Nearly all oriented lakes found in other areas (Bird 1967, Harry and French 1983, Stremiakov 1963, Grigoriev 1993), however, differ from the oriented lakes of arctic Alaska, which Carson and Hussey (1962) termed the “Northern Alaska Lake District”. The two prevailing winds there blow from opposite directions during the summer (NE and SW). The lakes are oriented perpendicular to these winds within a narrow range of orientation.

Numerous hypotheses have been introduced to explain oriented lakes and they can be classified in several groups: wind, wind-current, segmented lagoon, and structural control hypotheses. Intensive studies in the 1950s and 1960s focused mainly on hydrodynamics and inadequately addressed the importance of ice contents and thermal regimes in lake development. This region is characterized by a marine polar climate with very short and cold summers and by low permafrost temperatures. Under such conditions, lake thermokarst can be self-reinforcing where water depth is greater than the “critical depth” (about 5 ft). Where water depth is less than critical, however, the thaw bulb does not develop. In lakes with a deep central part (deeper than critical) the thaw bulb is limited to this central part (Sellmann et al. 1975). A typical oriented lake has a deep part, which is oriented in the same direction as the entire lake, and bars (shelves) along the windward sides. Presumably the deep parts were formed in a different climate than the current one.

Carson and Hussey (1962) recognized the importance of shallow shelves on the windward shores for limiting the enlargement of the lakes in the windward directions. While wave action along the prevailing wind should lead to fast erosion of windward shores, the formation of the shelves by the eroding sediments protect shore from further erosion by altering wave energy. This leads to an equilibrium profile (stable state) parallel to the prevailing winds, but not in the perpendicular direction. In their interpretation, the thermal insulation effect of the shelves due to accumulation of peat, the impact of sedimentary processes (as opposed to erosional) in the formation of shelves, and thermal erosion at the shores in directions perpendicular to the prevailing winds with constant removal of thawed soil, are all factors contributing to the reverse orientation.

We believe there is an alternative explanation of the thermal interaction of water and permafrost in the oriented lakes. The rate of lakeshore retreat with the constant exposure of permafrost can vary from dozens to hundreds of meters in one summer (Shur 1975, 1977), which is many times greater than the retreat of the shores of the thermokarst lakes anywhere in the permafrost region. Large peat accumulation on the shelves, in contrast with the central part of lake, was not substantiated by soil data presented by Carson and Hussey (1962). To protect permafrost under the shelves, there is no need to accumulate extra sediment of low thermal conductivity, because permafrost can persist under the shelves in shallow water (with a depth less than critical) because of the very cold climate. Wave action contributes to this protection by redistributing sediments on the shelves and filling depressions, which result from the thawing of ice wedges, thus forming a thermally protective layer above unmelted ice wedges. At Barrow, the active-layer depth on shelves is 1–2 ft and a thaw bulb occurs only under the central part of the lake where water depths are greater than the critical depth. The development of this thaw bulb, however, is a very slow process. It slowly alters stable-state conditions of the bars by thaw settlement at the inert border of the shelf. A new stable-state would form quickly, however, by wave action and erosion of a new portion of the shore. The importance of shelf formation on thaw lake orientation is illustrated by comparing thaw lake development on the coastal plain with that of the Colville Delta. Where the land surface on the coastal plain is underlain by sand sheets, lakes depths typically are 3-6 ft and the lakes are oriented in direction perpendicular to the prevailing wind. On the Colville, where the silty sediments are extremely ice-rich, thaw lakes are typically 11-15 ft deep. Protective shelves are not evident in the deep lakes in the delta and the thaw bulb is in close proximity in all directions. The lakes are weakly oriented parallel to the prevailing wind.

In summary, two processes affect lake orientation in the Arctic: thermokarst, which can spread under the shore with deep water, and thermal-mechanical erosion driven by the wind. In the Northern Alaska Lake District, mechanical erosion, however, is limited in the directions of the prevailing winds by the formation of shallow shelves, which dissipate wave energy and inhibit lake enlargement. The shorelines along the prevailing winds also are inaccessible to lake enlargement by thermokarst because they are isolated from the thaw bulb by shelves underlain by permafrost. In the direction transverse to the prevailing winds, the deepest part of a lake is not separated from the shore by a shelf and the thermal impact from water and the thaw bulb induce settlement by thawing ice-rich soil. Thus, thermokarst there is the main process of lake enlargement in that direction. Even more fundamental, is the requirement of an extremely cold climate, which allows the persistence of permafrost under shallow water. In areas with a warmer climate, however, the critical depth of water is much less than in northern Alaska (it is near zero for example in interior Alaska and in Central Yakutia). Therefore, thermokarst can develop under water of any depth and protective shelves do not form to alter the direction of lake enlargement. Consequently, development of the lakes along the prevailing wind is common in these warmer areas.

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Coastal Mapping and Change Detection using Oblique Coastal Videography, Kugmallit Bay, Canadian Beaufort Sea Coast

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Physical (as opposed to biological) coastal sensitivity to changes in land-use (e.g. shore protection, oil spills), environmental processes (e.g. waves, storms, currents, ice, etc.) and pollution is a function of morphology and materials that characterise the coastal zone. Mapping coastal sensitivity is undertaken by the Geological Survey of Canada using a combination of air photography, videography, beach and nearshore surveys and satellite imagery. Mapping is facilitated through the implementation of a Coastal Information System (CIS), which is based on basic physical elements of the nearshore, backshore and foreshore zone along homogeneous segments of the coast. This system has a lineage which extends almost 20 years. The current version utilises off-the-shelf Geographic Information System software and recently has been extended to include characteristics which are specific to high-latitude coasts. This has been done in order to investigate the sensitivity of the Canadian Beaufort Sea Coast to changes in environmental forcing due to climate change and to provide baseline information for delineation of Marine Protected Areas.

Kugmallit Bay is located at the mouth of the easternmost distributary of the Mackenzie Delta, close to potential oil and gas discoveries, which are as yet undeveloped. It is a summer feeding and breeding ground for large numbers of Beluga whales; the Hamlet of Tuktoyaktuk, lies on its eastern shore. It is the first high latitude area to be mapped using the CIS. Aerial videography was flown in 1984 and again in 1999 in order to map the coast and to detect changes in morphology and materials that may have occurred during that period. Mapping was undertaken at a scale of 1:50,000. The Kugmallit Bay region is dominated by low rolling tundra ranging to more than 100 m in elevation, but generally less than 30 m. Thermokarst lakes are very common and occupy about 30% of the land-area. Much of the coast consists of low coastal bluffs of unconsolidated and often ice-rich sand and silt, with relief provided in part by pingos. Ice is in the form of wedges and massive lenses, some of which extend below mean sea level. Coastal changes were mapped using clues from onshore features (e.g. lakes and streams). Extensive change was located principally along northwest facing shores which are more exposed to waves during storm-induced surges. Moderate changes appeared to be ubiquitous over the 15-year record. Typical bluff retreat rates are about 1–2 m a^{-1}, so moderate changes probably reflect several 10s of meters of erosion. Extensive retreat approaches 100 m or more (or retreat of 5–10 m a^{-1}).

Future plans include completion of the coastal mapping for the area from Cape Dalhousie to the Canada-U.S. border and development of a storm-surge model to identify locations, which are vulnerable to high water levels. Development of realistic scenarios for nearshore ice conditions throughout the open-water season and for changing storm intensity under future climate regimes are required in order to complete the analysis physical coastal sensitivity.

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On the New Cartographical Method for the Prediction of Shifting of the Sea Shoreline

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The isolines of the topographic and bathymetric maps represent an uniform mathematical surface, which is amenable to the geometrical transformations. This is used by studying the dynamics of the shoreline with the use of the method of plastic relief. Convexities are separated from the concavities according to the isohypses of the topographical maps (isobaths of the bathymetric maps) depicting the water bodies (oceans, seas, lakes etc.), and this is mathematically proved by the isoline of the null plan curvature. Thus, the discrete flow structure of the dry land and the adjacent bottom of the pool is revealed as a whole unit on the map. This structure builds up the regular geometrical figures, and each figure reflects the material composition of the rocks, which form the figures. The geological shift of precipitation specifies the geometry of the relief of the rocks, enabling the application of the mathematical methods for studying the dynamics of the shoreline.

The study of the coastal boundaries of the seas and oceans showed that those parts of the shores, which are related to the concavities (i.e. the relative depressions), can be washed out and fall most easily. The depressions are composed of the unconsolidated, weakly structurized redeposited products of the rock convexities, which possess a thicker primary schistose structure of the rocks; they are more tolerant to the destruction. This determines the curvilinearity of the shorelines and their curved shape; the convex forms of the Earth surface move forward in the shape of capes, and the concave ones recede in the shape of gulves. The change of the shoreline is uneven, and it is described geometrically on the new flow maps, allowing to increase the accuracy of the measures and to derive the justified mathematical equations of the motion.

The new cartographical structures are used for sampling the soils for determination of the absolute age by carbon dating. A comparison of the obtained data on the convexities and that of the concavities promotes a more precise determination of the relative rate of the shoreline motion.

The Massive Ground Ice Database

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A digital database on massive ground ice (DBGI) is under compilation in Moscow State University. The database contains information covering 133 sites in the arctic coastal zone, 108 located in Russia. The bibliographical list includes 400 titles, 87 of which are foreign publications. It covers research on massive ground ice in the Arctic for the last century. Information includes morphology and morphometry of the massive ground ice, lithology, ice content, lateral and coastal erosion. The DBGI holds plans and location maps of sea coasts of Russian Arctic. The first version of the database is now issued. More information is to be added the next 2 years.

The DBGI is in HTML format, which gives the opportunity to browse it using any JAVA-browsers. The graphical information is included in JPG and GIF formats. Primary information is digitized using Excel, Word, Photoshop software, which makes digital data convertible. Therefore the database can be used and filled up at any PC.

The Circum-Arctic Map of Permafrost and Ground Ice Conditions, scale 1:10,000,000, by J.Brown, O.J.Ferrians, Jr., J.A. Heginbottom, and E.S.Melnikov in JPG format (CAPS CD, 1998) is used as a base map. It was subdivided into 12 sections/regions. Borders of polygons are line convenient for PC usage. User can choose one of the polygons according to his/her regional interests, find a separate sheet linked through the point on the map with the list of references and relevant to this point (having more or less the same geographical coordinates). Reference ends in a number of key words. In addition to the reference, the database contains an abstract for each reference, published tables and figures containing information on morphology, morphometry, chemical composition of ice and enclosing deposits, isotope composition of ice. Figures, scanned in one of easy-accessible formats, represent geological sections and diagrams of various properties of ice and enclosing deposits.

This activity will result in a small-scale map of massive ground ice distribution in the Arctic. The study presented in this abstract was in part supported by INTAS, Grant #97-0484.

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Coastal Mapping of the Canadian Arctic Islands

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During the 1970s and 1980s there was an active coastal mapping program in the Canadian Arctic Archipelago by the Geological Survey of Canada (GSC). Aerial reconnaissance and ground surveys were initially completed along several of the inner islands including parts of Devon, Somerset, Bathurst, Melville, and Ellef Ringnes Islands and all of Cameron, Cornwall, King Christian, Lougheed and Lowther Islands. Later surveys were extended to the outer parts of the archipelago including the western shores of Baffin Bay and a small portion of the Arctic Ocean shores. Aerial oblique video was used in the later mapping. A coastal geology program was also undertaken by the GSC in the Canadian Beaufort Sea which is reported on separately by Steve Solomon (GSC).

The coastline of the inner Arctic Islands was mapped at 1:125,000 scale. Each coastline was progressively subdivided into homogeneous longshore units, cross-shore zones and individual features or components which were the building blocks used to define the physical characteristics and replicate shore types. The physical coastal characteristics were listed on coding forms and displayed on hard copy maps. For each shore unit there was a summary descriptor, information on backshore and terrain characteristics, shore zone character, and land use interpretation, e.g. trafficability. Sources of information were also listed. For the shore zone, the major processes effecting it, its morphology, slope, rate of change and the direction of sediment transport were listed in the coding forms. Unless measurements from shore monitoring stations were available, the rate of shoreline change and direction of sediment transport were based on the coastal geomorphology and were very elementary, i.e. ±. All of the mapping is in hard copy format, there is no digital data.

More than100 shore monitoring sites were established at representative shores within the Arctic Islands. Each monitoring site included surveys of 1 to15 cross-shore profiles, sediment samples, frost table measurements and photography. Some sites included nearshore surveys, stream discharge and wave measurements. Roughly 60% of the sites have only been measured once, while the rest have been measured more than twice. Twelve sites have repetitive surveys that span more than 10 years and two sites have information spanning 20 years.

Coastal change and the discharge of sediment is dependent on the physical setting, composition / geology, glacial history and relative sea level, character of ground ice/permafrost and the magnitude and frequency of processes reworking the coast. Within the inner Arctic Islands relative sea level has been falling consequently most of the unconsolidated, lower shores are beaches, with few low erosional cliffs and banks. Beach ridge development is a slow process of repetitive phases of building and retreat, before being abandoned as a raised feature. Sediment for beach building is scarce. There are however many shores with high erosional bedrock cliffs, with or without talus. The more conventional erosional shores, with wave washover and other transgressive features, described along the Beaufort Sea coast, are more common along the eastern and western portions of the archipelago where relative sea level is rising. Also, higher rates of shore erosion are measured in these areas because many are composed of recessive material, e.g. Tertiary deposits. Sea ice processes dominate coastal change along the northwestern Arctic Islands whereas waves and sea ice dominate change along the eastern archipelago. Glacial ice and ice shelf processes also are important in a number of locations.

Examples of coastal change are therefore best illustrated by using examples from across the archipelago, including the sandur and fiord shores of Baffin Bay, the gravel raised beaches of the inner islands, and the low lying sandflat and mud shores of the northwest islands and Arctic Ocean.

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Results of 20 Years of Observations of Coastal Thermoerosion in MarreSale, Kara Sea Region

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To establish observations of thermoerosion on the western coast of the Yamal Peninsula near the polar station Marre-Sale, in 1978 a portion of coast about 4.5 km long was equipped with more than 60 observational profiles together with Yuri Shur. Each profile was set perpendicular to the coast line and its location was determined. The coast under observation consists of a combination of sandy-clayey sediments, the second and the third marine terraces, 10- to 30-m height above sea level. Frozen sandy-clayey sediments contain constitutional, ice-wedge and tabular ground ice. The total ice content of deposits ranges from 10 to 60%. The amount of coastal retreat on each profile was measured annually at the end of a summer season.

The collected information is arranged into the digital database consisting of eight connected files, which contain data on morphology of coastal cliffs, composition and ice content of deposits, annual and summer air temperature for years of observations, as well as results of annual coastal retreat at each profile. The analysis of 20-year observations of thermoerosion shows that the process of coastal destruction in western Yamal is of a cyclic character. The periods with low rate of destruction are gradually replaced by the periods with high rate. On the basis of the available data it is possible to suggest that complete duration of a cycle is 18–20 years. Minimal rate of coastal retreat at the research site is 0.8 m/year (1997), maximal is 3.3 m/year (1990), and average for 20 years is 1.7 m/year. The phenomenon of cyclicity is known for collapsing sea coasts in temperate climates. Our studies show that this is observed in cryolithozone as well. Cyclicity of coastal thermoerosion is probably characteristic of the entire Arctic and is connected with the cycles of the arctic atmospheric and oceanic processes. In this connection it would be interesting to reveal conformity of cycles in various sectors of the Arctic.

The rate of coastal thermoerosion depends neither on lithology, nor on the height of coastal cliffs. There is no distinct correlation between this rate and mean summer air temperature, with the exception of abnormally warm years (for example 1990) when high mean summer air temperature coincided with increased amount of coastal destruction. Probably there is some threshold value of summer air temperature which starts to affect the coastal thermoerosion and causes appreciable increase of rates of coastal destruction. The high level of correlation (correlation more than 0.65) is established between the ice content in deposits and rate of coastal retreat. Data collection can be used as basis for estimating the influence of global climate change on dynamics of sea coast in the Arctic and for mapping coastal retreat.

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Ground Ice of the Baydarata Bay Coast (Kara Sea) and Its Influence on the Mechanism of Coastal Destruction

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It is known that ground ice controls both mechanism and rate of coastal destruction in the cryolithozone. Our estimates for the western Yamal show that the increase of total ice-content in coastal sandy-clayey sediments ranging from 10 to 60% of volume results in increase of retreat rate of approximately two-fold. These observations can provide the basis for coastal classification. Regularities already understood while studying the Baydarata Bay coasts (Yamal Peninsula from the east and Yugorsky Peninsula from the west) allow us to suggest several mechanisms of coastal destruction depending on ice type and content.

1. It is established that in the coasts built of clayey deposits at least in the toe of the cliff with low ice content and massive cryostructure, wave-cut notches are formed. Subsequently, blocks of frozen deposits fall and are washed away. The rate of destruction of such coasts is minimal (1-1.5 m/year). Ice-wedges are contributing factor to block falls and determine the block size. The rate of retreat here is only limited by the rate of wave-cut notch formation. Extent of such fragments is hundreds of meters along the shoreline.

2. There are sites with ice content in clayey deposits of up to 40–60%, with reticulate or blocky-reticulate cryostructure. In this case, the basic mechanism of coastal destruction is thaw and flow of viscous material to the base of the coastal cliff with subsequent wash. The differences with the first type are in higher rate (2–3 m/year) and smaller fragments (dozens of meters along the shoreline).

3. The highest retreat rate is characteristic of the sites enclosing massive (tabular) ground ice. The main mechanism of destruction here is “thermodenudation” which is retreat of an ice slope as a result of a combination of several active processes, including earthflows, slumps, thermokarst, lateral thermoerosion, and nivation. The rate of destruction is very high, up to 10 m/years. Thermocirques are formed as a result of this process. After all the ice body thaws out,

thermocirques become stabilize. The thermocirque size is dozens to several hundreds of meters, the shoreline of the specific shape can be several kilometers long.

Observations on Yamal and Gydan peninsulas can be used to compile a classification and a map of coastal types and retreat rates. Study of destruction mechanisms should be continued. The main task for this is abundant measurements of constitutional and massive ground ice content in clayey deposits.

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Deltas in the Arctic

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Arctic deltas are dynamic, complex, remote, and among the least modified by humans. They, like other deltas, are the product of interactions among the lithosphere, hydrosphere, atmosphere, biosphere, and cryosphere. Most are dominated by long and cold winters, a surface that is covered with snow and ice most of the year, and underlain by permafrost. Present-day arctic deltas range in size from those small ones that are forming in recently tapped lakes to some of the world's largest including the Lena River delta that is 32,000 km^2 in area. As elsewhere, arctic deltas owe their present position to the recent rise in sea level. Although basically similar to other deltas in the world, they also have forms and processes that are unique to the Arctic including ice wedges, ice-wedge polygons, and thermokarst lakes, among others. One of the most important processes operating in arctic deltas is breakup and the flooding that precedes, accompanies, and follows it. In the case of the Colville River delta in northern Alaska, this part of the hydrologic year lasts only about three weeks. Nonetheless, it is during that period of time that most of the annual sediment load is transported down the river to be deposited in both the subaerial and subaqueous portions of the delta. The sequence of the river's hydrologic and geomorphic events in other Arctic deltas is basically the same as that of the Colville.

Seismic Shot Hole Evaluation of Massive Ground Ice in the Richards Island, N.W.T., Area.

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Thousands of shallow boreholes drilled for seismic surveys (seismic shotholes) in support of oil and gas exploration cover large parts of the Beaufort Sea coast in the Mackenzie Delta area. It is well known from coastal exposures, geomorphologic investigations, various geophysical surveys, and geotechnical drilling that ground ice is abundant in this area. Seismic shotholes potentially provide an additional detailed means of estimating ground ice occurrence on a regional basis. The boreholes are drilled by air rotary equipment and yield only cuttings blown to the ground surface. As a pilot study, logs of the cuttings have been compiled with information on ground-ice intersections and broad characterization of sediment associations. These data have been compiled using a GIS system with attributes assigned to material type with standard overlays of topography, surficial geology and geothermal data. Initial evaluation of the pilot study reveal the value of the spatial data especially in gaining an appraisal of the significance of ground ice in areas where no surficial exposures or other data are available. The high frequency of ground ice in glaciofluvial terrain is a good example as these areas rarely contain ground-ice exposures and normally on a geotechnical basis alone might be considered to be ice poor. However, the quality of the information gained from the shothole records, and the precision with which they can be interpreted, must be carefully evaluated if they are to be used as a source of ground-ice information.

ARCTIC COASTAL DYNAMICS WORKSHOP
Woods Hole, Massachusetts
November 2–4, 1999

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