Sedimentology of Arctic Fiords Experiment (SAFE): Project Introduction

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ABSTRACT. The Geological Survey of Canada’s project SAFE (Sedimentology of Arctic Fiords Experiment) was initiated in 1981 and is being carried out in a series of fiords situated along the east coast of Baffin Island. SAFE emphasizes the study of the Quaternary history and modern processes of arctic fiord environments. Project participants are interested in evaluating the significance of the comparatively rapid process rates and of the high-resolution sedimentary records that typify these settings.

The key objectives of SAFE include: 1. To understand sandur development and the character of the resultant facies. 2. To understand the time-dependent influences of rivers, tides, waves, wind and deep-water renewal on fiord circulation and sedimentation patterns. 3. To use the geological record of raised marine deposits in establishing late Quaternary history within and between fiords.

Following a reconnaissance of 10 fiords along the east coast of Baffin Island in 1982, 3 were selected for detailed study during the 1983 field season (Cambridge, Ítirbilung, McBeth). The 1982 and 1983 investigations utilized the oceanographic research vessel CSS Hudson as an operations base. During both surveys, core sampling, CTD profiling, geophysical mapping and other heavy work were carried out from the Hudson up to the 100 m isobath. The shallow water operation was supported by two launches outfitted with equipment to carry the oceanographic and geological programs into nearshore uncharted areas. Field parties were landed to study raised marine deposits and glacial features. The 1983 survey was preceded by a helicopter-supported program that succeeded in mooring and recovering several strings of current meters and sediment traps near the heads of Cambridge and Ítirbilung fiords.

Key words: sediments, Quaternary, fiord, arctic, Baffin Island, inner shelf

INTRODUCTION

Fiords are deep, glacially modified estuaries common to high-latitude mountainous coastlines including North and South America, Europe, Greenland, U.S.S.R., Spitsbergen, Iceland, New Zealand, and South Georgia. They are considered to be environmentally sensitive estuaries because of their slow flushing times, a feature unique to fiords (Syvitski and Skei, 1983) and which is among the most important requisite conditions for anthropogenic waste disposal (Skei, 1981). Fiords also command attention for their intrinsic scientific identity: process rates are fast and environmental gradients are large. Attempts at modelling these natural processes in the field often point to fiords as ideal extensions of the scientists’ laboratory flumes (Hay et al., 1983). Fiord deposits have a good potential for providing a comparatively high-resolution sedimentary record that reflects local terrestrial and marine processes (Schafer et al., 1983).

Arctic fiords can be defined as those geomorphological features subject to periglacial processes on land and influenced by the presence of sea ice through at least part of the year (Gilbert, 1983). In Canada, these criteria can be applied to fiords of the eastern arctic archipelago from Ellesmere Island to Baffin Island. Studies of the oceanography and circulation characteristics of arctic fiords have been reviewed by Lake and Walker (1976). The results of the first long-term measurements of currents and circulation characteristics in an arctic fiord are described by Lewis and Perkin (1982). Reconnaissance studies of arctic fiord sediments include the work of Buckley (1971), Bornhold (1976), Berthois (1969), Boulton (1982), Elverhoi et al. (1980), Gilbert (1978, 1980, 1982), Herman et al. (1972), Knight (1971), Lewis et al. (1977), and Prior et al. (1981). Their contributions to our overall understanding of fiord sedimentology have been reviewed recently by Gilbert (1983).

1SAFE contribution number 1.

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Complex logistic support requirements and an inhospitable climate have made detailed studies of arctic fiords difficult. Knowledge of the nature of these systems is therefore still fragmentary and highly qualitative. Because of an awareness of these shortcomings, the Geological Survey of Canada, in concert with scientists at several universities, initiated a multidisciplinary project to investigate arctic fiords. The project began with some 30 fiord experts from nine universities across five countries and three Canadian federal government departments. Project SAFE (Sedimentology of Arctic Fiords Experiment) began in 1982. By way of this paper, we introduce the project objectives, strategies and field approach as a prelude to future SAFE research manuscripts that will appear in Arctic.

OBJECTIVES

The present conceptual model (Fig. 1) of the interaction of the processes that drive or inhibit arctic fiord circulation and thus modulate sediment erosion, transport and deposition follows that of Gilbert (1983). Salient features include: 1) the effects of a lengthy presence of sea ice on water stratification; 2) flood-dominated fluvial discharge events occurring within a short runoff season; 3) the importance of the Coriolis force on circulation; 4) the breakup of surface stratification during the open-water season through high-energy wind mixing; and 5) the influence of tidewater glaciers on proximal turbulence and sediment deposition. Our objectives were founded upon the following insights specific to arctic fiord sedimentology: 1) the bulk of fluvial-sediment transport can occur within a few days (Church, 1972); 2) extreme winds and lack of vegetation promote large-scale aeolian transport, limited only by the availability of finer-grained material (Gilbert, 1983); 3) side-entry glacial, glaciofluvial and fluvial input of sediment can be substantial (Ostrem et al., 1967); 4) rock falls, slides and dirty avalanches are commonly released along the walls of arctic fiords in association with the hydro-fracturing process and can contribute significantly to the coarse fraction of the marine sediment (Church et al., 1979); 5) there are excellent ex-
posures of isostatically-raised glaciomarine and fluvio-deltaic terraces (Andrews, 1978); 6) the dynamics of tidewater glaciers are important modifiers of the stratigraphy within fiords (Powell, 1981; Elverhoi et al., 1980); and 7) the low concentrations and glacier-influenced distribution patterns of organic material and inorganic nutrients have important ecological implications (Pearson et al., 1985). Taken together, this suite of natural phenomena provides a broad perspective on the dominant geological, oceanographic and climatological processes operating within arctic fiords. The key objective of SAFE is to bring together the elements of an interdisciplinary team that can evaluate the links between these processes from a comprehensive point of view. In formulating project goals, emphasis was placed on the Quaternary history of these inlets and on the establishment of a historical baseline to which modern processes can be compared.

The questions being addressed by the geologists involve problems related to variations in annual river discharge and their relationship to sediment flux, fiord turbidity, resuspension events, and to the formation and breakup of sea ice. Oceanographers are contributing to the project through their evaluation of the time-dependent influences on sediment deposition of tides, wave activity, and deep water renewal in relation to overall fiord circulation patterns. They have placed specific emphasis on seiche events, internal wave activity on prodelta slopes and polynya dynamics.

Another goal of SAFE is to utilize real time observations as inputs to sediment transport models. The monitoring data can also be used to calibrate the relationship between proxy climatological and paleoecological signals, contained in well-dated marine sediment cores. The distribution of modern end-member assemblages will contribute to the interpretation of Pleistocene sediments that contain similar assemblages. Data for models are selected to reflect the spectrum of key environmental conditions presumed to have existed within these fiords at some time over the past 100 000 years.

The Quaternary program was developed to investigate the late Foxe and neo-glacial extent of glaciers in the fiords and their effect on sedimentological processes. In particular, the history of glaciation between 10 000 and 40 000 BP is currently unknown (J.T. Andrews, pers. comm. 1984).

The geochemical program will focus on the identification and preservation potential of redox discontinuity zones within the sea floor. Redox reactions involving degradation of organic matter may be retarded in arctic fiords, as compared with subarctic or temperate fiords, because of the generally low concentrations of land-derived organic debris. It is also expected that the intermittent pulses of sediment emanating from meltwater rivers or tidewater glaciers may cause wide variations in geochemical reactions.

The geotechnical program was initiated to relate the salient sedimentological and geotechnical properties of the sea floor sediments to the wide variety of slope-dominated environments contained within the fiords. In particular, details of the facies relationships between the many forms of mass movement and sediment gravity flow deposits will be investigated.

**FIORD SELECTION STRATEGY**

The most important selection criterion used to identify Canadian fiords for this study was the open-water interval for research ship-based sampling and surveying, our primary field method. High arctic fiords, such as the Nansen Sound-Greely Fiord system of Ellesmere Island, were not considered because of their short open-water season (=15 days). Project SAFE, then, was constrained almost from its inception to fiords situated along the 2000 km long eastern coastline of Baffin Island (Fig. 2). The island spans a wide range of climatic, geomorphic and oceanographic end members and is characterized further by a relatively long open-water (sea-going) season (=45 days).

The second selection criterion was to have some prior information on the bathymetry within the fiords so that: 1) ship time could be spent primarily on scientific investigations rather than basic hydrography and 2) there would be some prior knowledge of basin and sill depths, a prerequisite for ocean exchange predictions (Stigebrandt, 1981). Of the approximately 290 fiords incising the eastern coast of Baffin Island, only 40+ had been sounded previously. Of these, most had little more than a couple of axial lines surveyed by the Canadian Coast Guard ship D'iherville in 1965 and 1966. Exceptions included the moderately detailed surveys of: 1) DEW line stations (e.g., Sunneshine and Ekalugad fiords); 2) those with settlements (e.g., Strathcona Sound, Pond Inlet, Pangnirtung Fiord); and 3) those covered in the surveys of Knight (1971) and Gilbert (1980), i.e., Ekalugad, Maktak, Coronaion and North Pangnirtung fiords.

Ten fiords were investigated in 1982 (Fig. 2, Table 1). Their even distribution along the Baffin coast ensured the traverse of a number of important strategic gradients (Maxwell, 1980). These include: 1) a rapid northerly decrease in tidal range (7 m to 1 m); 2) a northerly decrease in ice free days (60 to 30); 3) a northerly decrease in the active layer above permafrost (85 cm to 25 cm); 4) a northerly increase in June mean daily global solar radiation from <500 langleys-day⁻¹ at Frobisher to >755 langleys-day⁻¹ at Pond Inlet; 5) a northerly decrease in mean annual runoff (Fig. 3; 300 mm to 125 mm); 6) a northerly decrease in mean annual temperature (Fig. 3); −7.5°C to −13°C; 7) a northerly decrease in the mean annual totals of growing degree-days (100 to 40); 8) a northerly decrease in the mean total rainfall (200 mm to 75 mm); and 9) a northerly decrease in mean total snowfall (600 cm to 100 cm). In addition, the fiords that were selected provide a wide range of: 1) fiord-head drainage basins (e.g., the McBeth basin is =20 times larger than the Sunneshine basin); 2) ice dominance in the fiord-head hinterland (e.g., 3% in Cambridge, compared to 80% in Coronation); 3) river valley gradients and thus bed load competence; 4) fiord morphology (sill and basin depths, fiord lengths and widths); and 5) complexities in side-entry (tributary) glaciers and glacial streams. The final choice was also based on predicted sedimentation levels in the fiords estimated from the size of the active sandur surfaces (air photos) and from the size of the fiord surface suspended sediment plume (landsat infra-red images).
SAFE EXPERIMENT: INTRODUCTION

Baffin Island is large, the third largest island on earth with a surveyed area of 507 451 km², of which 35 890 km² is ice covered. The mountainous zone contains all the major ice fields and glaciers with the exception of the Barnes Ice Cap (Fig. 2). The fiords first dissect the Baffin Coastal Lowlands and extend landward into the Davis Highlands, a rugged Precambrian terrain with peak elevations considerably higher along the flanks of the fiords compared to adjacent inland areas (exceptions are the Cumberland Peninsula fiords) (Fig. 4). The Davis Highlands range in elevation from 1000 to 2000 m and have a maximum elevation of 2300 m. The Baffin fiords fall within zones of rock desert vegetation and arctic stony lichen and heath. The duration of winter along the fiord coast (i.e., mean number of days with mean daily temperature below 0°C) is 280 days (9.5 months). In general, Baffin fiords are relatively colder than west Greenland fiords.

FIELD STRATEGIES AND METHODS

The SAFE program consists of three field seasons of intensive sampling and surveying (1982, 1983 and 1985) Details of the 1982 and 1983 field seasons can be found elsewhere (Syvitski, 1982; Syvitski and Blakeney, 1983; Asprey and Johnston, 1984; and Syvitski, 1984). In general, the field
operations reflect four distinct logistic strategies. The large research vessel CSS *Hudson* was used primarily for heavy sampling and offshore geophysical survey work. Additionally, *Hudson* provided an operations centre in each of the fiords for two 9-metre launches and two 5-metre Boston Whaler outboard motor boats. The smaller vessels were deployed daily from the mother ship to conduct shallow water (\(<100\) m) surveys and to transport work parties to various points of interest along the fiord shoreline. A helicopter was used to install monitoring instrumentation near the head of Itirbiling and Cambridge fiords and to carry out sedimentological surveying and sampling over a range of geological settings.

Operations on *Hudson* during the 1982 and 1983 surveys can be classified into four major categories: sampling, geophysical surveying, data processing, and general logistic support. These activities involved a ship crew of about 70 and 26

<table>
<thead>
<tr>
<th>Fiord</th>
<th>= Ice Free Days</th>
<th>Tides (m)</th>
<th>No. of Sills (and Depth (m))</th>
<th>Fiord Length (km)</th>
<th>Mean Depth (m)</th>
<th>Max Depth (m)</th>
<th>Fiord-head Drainage Basin Area (km²)</th>
<th>% Ice</th>
<th>Avg. Valley Slope</th>
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</thead>
<tbody>
<tr>
<td>Pangnirtung</td>
<td>60</td>
<td>5.1</td>
<td>7.3</td>
<td>(1):15</td>
<td>43</td>
<td>3.1</td>
<td>180</td>
<td>556</td>
<td>53</td>
</tr>
<tr>
<td>Sunneshine</td>
<td>60</td>
<td>2.2</td>
<td>4.0</td>
<td>(1):64</td>
<td>60</td>
<td>3.6</td>
<td>7145</td>
<td>96</td>
<td>19</td>
</tr>
<tr>
<td>N. Pangnirtung</td>
<td>60</td>
<td>0.9</td>
<td>1.4</td>
<td>none</td>
<td>45</td>
<td>3.5</td>
<td>480</td>
<td>1329</td>
<td>57</td>
</tr>
<tr>
<td>Coronation</td>
<td>60</td>
<td>0.9</td>
<td>1.4</td>
<td>none</td>
<td>30</td>
<td>3.2</td>
<td>600</td>
<td>850</td>
<td>80</td>
</tr>
<tr>
<td>Maktak</td>
<td>60</td>
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<td>1.4</td>
<td>none</td>
<td>65</td>
<td>2.3</td>
<td>320</td>
<td>898</td>
<td>53</td>
</tr>
<tr>
<td>Tingin</td>
<td>50</td>
<td>0.8</td>
<td>1.1</td>
<td>(1):180</td>
<td>56</td>
<td>4.6</td>
<td>520</td>
<td>298</td>
<td>20</td>
</tr>
<tr>
<td>Itirbiling</td>
<td>50</td>
<td>0.8</td>
<td>1.1</td>
<td>(1):110</td>
<td>64</td>
<td>3.0</td>
<td>430</td>
<td>1281</td>
<td>28</td>
</tr>
<tr>
<td>McBeth</td>
<td>40</td>
<td>1.0</td>
<td>1.3</td>
<td>(3):70,200,250</td>
<td>120</td>
<td>Var.</td>
<td>570</td>
<td>1629</td>
<td>4</td>
</tr>
<tr>
<td>Inugsuin</td>
<td>35</td>
<td>1.0</td>
<td>?</td>
<td>(3):120,380,220</td>
<td>92</td>
<td>5.7</td>
<td>630</td>
<td>220</td>
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<td>Clark</td>
<td>30</td>
<td>1.0</td>
<td>1.3</td>
<td>(2):108,185</td>
<td>110</td>
<td>Var.</td>
<td>760</td>
<td>171</td>
<td>26</td>
</tr>
<tr>
<td>Cambridge</td>
<td>30</td>
<td>1.0</td>
<td>1.4</td>
<td>(3):106,230,330</td>
<td>160</td>
<td>3.6</td>
<td>708</td>
<td>584</td>
<td>3</td>
</tr>
</tbody>
</table>

1Pangnirtung is included in the table as an originally selected fiord; however, heavy ice conditions did not permit access to this system and Sunneshine Fiord was substituted.

FIG. 3. Mean annual run-off isolines and mean annual isotherms for the eastern Arctic.
SAFE EXPERIMENT: INTRODUCTION

Each of the two launches was equipped to carry out survey and sampling work especially in uncharted nearshore environments. The hydrographic launch used RADAR fixing and a wide-beam echo sounder to measure water depths across the axis of each fiord. This launch was also set up to collect sediment samples and to deploy a "Dart" unmanned cable-controlled submersible. The second launch was equipped with a Klein side-scan sonar, a high frequency acoustic profiler, a portable CTD, water and grab samplers. Profiling concentrated on fiord-head prodelta and side-entry glacier localities. Both launches were used to aid in the recovery of current meter-sediment trap moorings deployed several weeks earlier by helicopter.

Two Boston Whalers ferried shore parties to and from the Hudson and carried out light grab sampling tasks in shallow (<50 m) subtidal environments. The Whalers also provided ice-breaking support for the launches during mooring recovery operations. One land party concentrated its efforts on glacial and fluvial-marine sediment transport processes primarily in fiord head delta areas. A second group of geologists investigated the dynamics of glacier retreat using facies mapping and lichenometry dating techniques. Specialized sampling programs were carried out to evaluate the placer potential of heavy mineral deposits in delta, prodelta and beach environments and magnetic susceptibility of fiord sediments. The information derived from these samples was supplemented by data obtained with a prototype magnetic particle trap moored offshore using helicopter support.

The third and final phase of project SAFE has been planned for September 1985. It will involve a combination of helicopter-transported shore parties and the research vessel M/V Pandora II; the Pandora also supports the manned submersible Pisces IV (for submersible capabilities see Syvitski et al., 1983) which is being used to investigate geomorphological features observed on side-scan SONAR records during the 1982 and 1983 surveys. It is hoped that an outgrowth of SAFE's multidisciplinary approach will continue in the future through the efforts of university participants. Interested researchers should contact Dr. R. Gilbert (Department of Geography, Queen's University, Kingston, Ontario, Canada K7L 3N6), who has been selected by a committee of SAFE participants to coordinate such future research.

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REFERENCES


1980. (Unpub. ms.) Environmental studies in Maktak, Coronation and North Pangnirtung Fjords, Baffin Island, N.W.T. Final report of research supported by Petro Canada Exploration Inc., NSERC and Dept. of Geology, Queen’s University, Kingston, Ontario. 97 p.


