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Geostatistical mapping and spatial variability of surficial sediment types on the Beaufort Shelf based on grain size data

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ABSTRACT

The paper describes an approach for a quality controlled mapping of grain sizes and sediment textures for the Beaufort Shelf in the Canadian Arctic. The approach is based on grain size data collected during the *Nahidik Program* (2005–2009) and earlier. A replenishment of grain size data since the 1980s, as well as the consideration of correlating parameters (bathymetry, slope and sediment input) to a cokriging algorithm, amends the former way of mapping the surficial sediments of the Beaufort Shelf. The cokriging analysis showed that the simulation of a sediment input by the Mackenzie River, modeled as a cost–distance function, was the key variable in reducing the errors of the output estimate.

Furthermore, the approach compares the geostatistical interpolation methods of ordinary kriging and cokriging and recommends the use of a combination of both. The predicted mean standard errors showed that in this study cokriging was the superior interpolation method for clay, silt and sand while ordinary kriging was more suitable for gravel.

A new sediment texture map, based on the grain size maps, is provided according to commonly used grain size and sediment type classification systems.

1. Introduction

The nearshore Beaufort Sea is a sensitive marine environment that is also the focus of oil and gas exploration. Offshore, the Beaufort Sea contains large potential reserves of hydrocarbons. Any future exploitation of these resources will present unique engineering challenges and will require an understanding of the processes that govern stability, nearshore morphology and sediment properties in the extensive shallow coastal zone of the Beaufort Shelf. Knowledge of the surficial sediment distribution is, therefore, necessary to provide a framework for understanding sediment stability, sediment transport, platform foundation conditions and to balance engineering challenges with environmental concerns, resource development and precautionary sustainable management. Management of offshore resources has always been constrained by a lack of high-quality information on the marine ecosystem. However, additional surficial grain size data coupled with precise positioning using Global Positioning System technology, and the utilization of new and contextual analysis methods provides an innovative method of gaining information over wide areas of the Beaufort seafloor.

The Canadian Beaufort Sea (Fig. 1) is an extremely dynamic environment susceptible to reworking by both arctic marine and periglacial processes. Its sediments are subjected to many of the normal processes affecting temperate latitude sediments, such as wave action, tides and storm surges as well as many uniquely arctic processes, such as ice push, thermo-erosion and thaw subsidence. In addition, normal offshore processes may be strongly modified by the uniquely arctic nature of the system; for example, the presence of offshore sea ice limits wave activity and even during the short open-water season, offshore ice affects the fetch window available for wind-wave generation (Harper, 1990).

The erosional nature of the Mackenzie delta front and the drowned morphology indicate that the delta is undergoing transgression, resulting in minimal water depths for sediment accumulation (Hill et al., 2001). However, bar accretion still occurs within large embayments at the mouths of some distributary channels (Jenner and Hill, 1998). In general, the nearshore area (seaward of the Holocene delta) is very shallow. Water depths are less than 2 m at distances in excess of 15 km from the shore. Mean tides are 0.3 m and large tides are up to 0.5 m, whereas winds may raise water levels as much as 2.4 m (Hill et al., 2001) or lower them by up to 1 m (Henry, 1975).

According to Pelletier (1984) fine-grained sediments occupy most of the seabed, particularly in the central part of the southern Beaufort Shelf and seaward of the 10 m isobath. This is the area of clay deposition and indicates relatively low hydrodynamic conditions. Silt is found chiefly from the 10 m isobath landward into the nearshore, from Mackenzie Bay to Kugmallit Bay in the east. Sand is common along the eastern edge of Mackenzie Trough, in the coastal zone, seaward of the 2 m isobath, and on bars, spits and offshore islands, due to increased sorting action by waves and currents which remove finer sediments. A considerable amount of sand deposition occurs on the eastern portion of the

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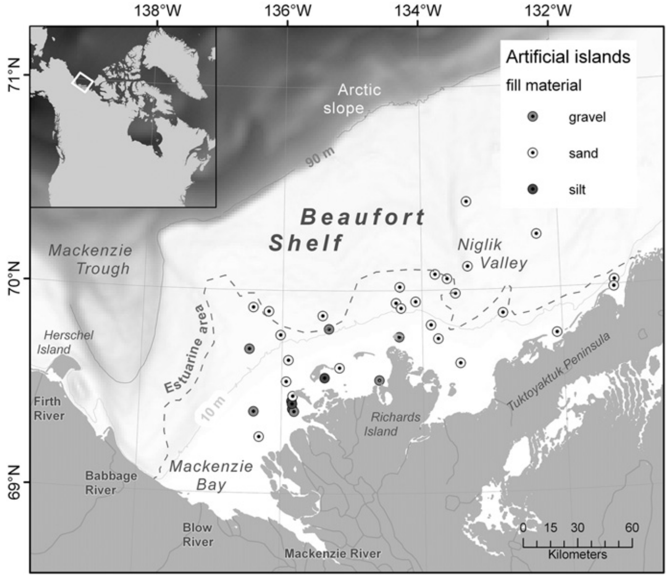

Fig. 1. Location map of the Canadian Beaufort Shelf showing the distribution and fill material of artificial islands. The textural dots refer to artificial islands.

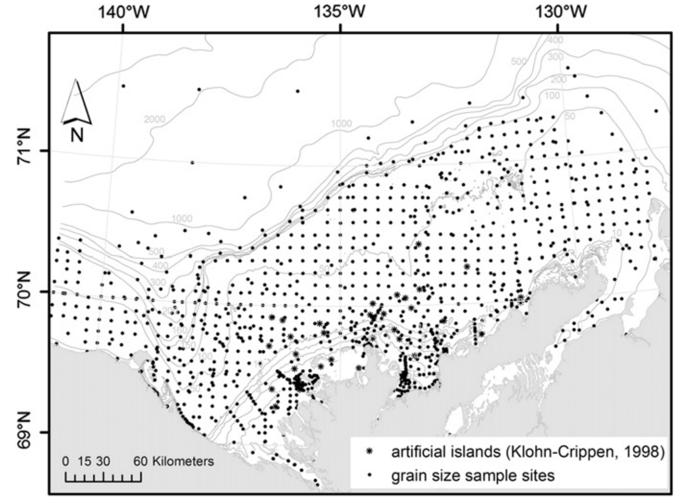

Fig. 2. Spatial data distribution of grain size samples and artificial islands according to Klohn-Crippen (1998).

shelf where some erosion by bottom currents exposes older beach deposits (Pelletier, 1984). Gravel is also common in this area, but is found in much higher quantities along bars, beaches and at the base of coastal cliffs undergoing erosion. The offshore sand and gravel deposits west of Herschel Island are due mainly to ice-rafting. Here, sediments are deposited from ice impeded by the winter freeze-up and impinged against western Herschel Island. Isolated occurrences of sand and gravel on the outer shelf, to the east, may also be due to ice-rafting (Pelletier, 1984).

Most of the sediment is deposited from the Mackenzie, Firth, Babbage and Blow Rivers. A sediment plume defining an estuarine zone (Fig. 1) extends about 55 to 70 km north of the coastline. The Mackenzie River is the largest river on the North American side of the Arctic with an annual freshwater discharge of 330 km^3 and an annual sediment load of 127 Mt to the Canadian Beaufort Shelf (Macdonald et al., 1998). Massive quantities of predominantly fine-grained sediment and associated organic carbon are transported into the Arctic Ocean during the freshet from May to September (Forest et al., 2007; Hill et al., 1991; Walker et al., 2008). Under the influence of the Coriolis force, this plume moves easterly, and sediments derived from coastal erosion on the seaward fringes of the estuary and Tuktoyaktuk Peninsula may be entrained in this system. West of Shallow Bay, sediment movement in the nearshore is also controlled by coastal currents (Pelletier, 1984). O'Brien et al. (2006) note that the Mackenzie River is the largest source of sediment to the arctic region; therefore the discharge of the Mackenzie River is the major component for the geostatistical modeling of Beaufort Shelf sediments. The goals of this study are:

- to use and describe an appropriate interpolation method achieved by comparing ordinary kriging and cokriging
- to deliver quality controlled results by predicted standard errors of each sediment class
- to provide a series of new georeferenced grain size maps and a sediment texture map of the Beaufort Shelf based on geostatistical interpolation.

2. Material and methods

Realistically, it is impossible to get exhaustive values of data at every location because of practical constraints. Thus, interpolation is fundamental to the graphing, analysis and understanding of 2D data. Different possibilities exist to describe the relationships (autocorrelations) of punctual data. They are based on the assumption that the autocorrelation of the data is not dependent on the absolute (geometrical) location of the sites, but on the spatial distribution of the sites relative to each other in distance and direction (Isaaks and Srivastava, 1992). Geostatistical methods like kriging (Krige, 1951; Matheron, 1963) include the degree of spatial autocorrelation and the directional dependency (anisotropy) when predicting measurements. The degree of spatial autocorrelation can be assessed by applying variogram analysis, where semivariances are calculated for defined distance classes and plotted against the separation distance. The resulting experimental variogram and cross-validation analysis are then the basis for finding an adequate variogram model that may be used for the kriging

Table 1
Sediment grain size data used for geostatistical interpolation (1969–2008).

Year of sampling	Reference	Number of samples
1969–2008	Expedition Database (ED) (2010)	1114
1976	EBA Engineering Consultants Ltd. and Beaufort-Delta Oil Project Limited (1976)	42
1976	Samples located using offsets from transponder; locations found in a field notebook provided by Dr. H. Kerfoot (1976).	22
1987	Kauppaymuthoo (1997)	13
1970	Dewis (1971)	49
1969–2008		1240

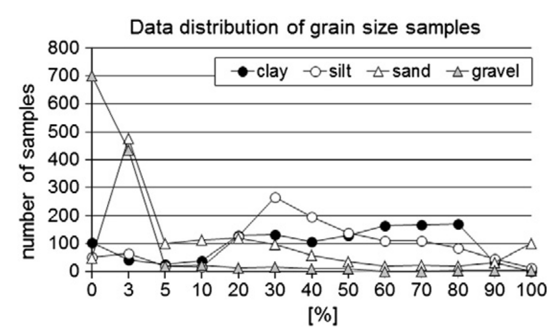

Fig. 3. Data distribution of the clay, silt, sand and gravel components of grain size samples, classified after Wentworth (1922), plotted against the total number of samples (1240) used in this study.