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Diffuse spectral reflectance of surficial sediments indicates sedimentary environments on the shelves of the Bering Sea and western Arctic

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ABSTRACT

Visible diffuse spectral reflectance (DSR) has been described by previous workers as an efficient tool for extracting lithological compositions: clay minerals, iron oxyhydroxides, carbonates and diatoms in sedimentary material. The spatial patterns of these components are essential to understanding the processes driving their distribution and accumulation in the marine environment. Some of these processes include sea ice variability, nutrient supply, current flow patterns, current strength, sediment supply, provenance and bathymetry.

The DSR derivatives and Varimax-rotated principal component analysis (VPCA) of the spectral data collected from 234 core samples identified five leading components that account for variations in sediment lithology of the surface samples from the Bering Sea and western Arctic. These spectral components were then matched to spectral standards to identify the mineral assemblages responsible for them. The components responsible for the VPCA trends are chlorite + muscovite; goethite + phycoerythrin + phycocyanin; smectite; calcite + dolomite; and illite + chlorophyll a.

The spatial pattern of the inorganic components is indicative of provenance and processes controlling their transportation and depositional patterns, while the organic components are indicative of areas of primary productivity and driving mechanisms. The chlorite + muscovite assemblage which is sourced dominantly from the Yukon River has maximum values on the Bering Sea shelf; this is the source of the chlorite + muscovite transport to the Chukchi Sea. The chlorite + muscovite assemblage also has a main transport route to the Aleutian basin in the northern Bering Sea shelf. The Chukchi Sea on the western Arctic Ocean shelf is a region of highly reducing condition. This is based on the lowest values for the goethite + phycoerythrin + phycocyanin assemblage, supported by the high carbonate concentrations at this location. The carbonate distribution pattern on the Bering Sea shelf also appears to be tidally influenced. This is because their spatial pattern divides the Bering shelf into three domains, which are similar to the three hydrographic domains on the Bering shelf—a function of tidal influence. The smectite assemblage reaches maximum values along the coast of the Chukotka Peninsula in the Chukchi Sea, denoting the Chukotka Peninsula as a major source area of smectite, and supporting the notion for volcanically derived sediment to the Chukchi Sea. Another likely source of smectite to the Chukchi Sea is via the Bering Strait. The illite in the illite + chlorophyll a assemblage shows maximum values and distribution on the western Arctic Ocean shelf, indicating the western Arctic Ocean shelf to be a main province of illite. All the high values of the illite + chlorophyll a component on the Bering Sea shelf are chlorophyll a from diatoms.

Our results support the usefulness of the DSR method as an effective and efficient tool for provenance analysis, and understanding the processes controlling sediment and biologic distribution, in this case, in the marine environment.

1. Introduction

The Arctic has drawn considerable attention recently due to the significant observable changes taking place there, and the impact of those changes on the global climate system. Some of these changes include a reduction in sea ice coverage, increased melting of the Greenland ice sheet, permafrost thawing and rising surface temperatures (e.g., Comiso et al., 2008). Changes in ice cover result in changes in albedo, which in turn have a feedback effect on climate.

To fully understand the role of the Arctic in global climatic change, the role of the Arctic in past climatic changes must be understood (Viscosi-Shirley et al., 2003a). These changes are recorded in sediment and sedimentary rocks. Understanding these past climatic changes requires knowledge of the surface sedimentary processes in the Arctic (Viscosi-Shirley et al., 2003a) and environments.

Workers such as Naidu and Mowatt (1983), Moser et al. (1984), Naidu et al. (1996), Kalinenko (2001), Viscosi-Shirley et al. (2003a), Stein (2008) and Ortiz et al. (2009) have used clay mineral assemblages

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as a tool to understand the surface Arctic sedimentary processes with regard to provenance, water mass circulation and hydrodynamic conditions. Other applications of clay minerals abound: Moser et al. (1984) discussed their potential when placing drill rigs, to infer potential spill dispersal patterns. They have also been used by Viscosi-Shirley et al. (2003a,b) to estimate the dispersal and deposition of contaminants in the Arctic.

Previously, the distribution patterns of clays were largely determined by X-ray diffraction (XRD; Naidu and Mowatt, 1983; Moser et al., 1984; Naidu et al., 1996; Kalinenko, 2001; Viscosi-Shirley et al., 2003a; Stein, 2008; Ortiz et al., 2009). Visible derivative spectroscopy employing DSR data provides another approach to lithologic reconstruction (Deaton and Balsam, 1991; Balsam and Wolhart, 1993; Balsam et al., 1995; Balsam and Beeson, 2003; Balsam et al., 2007; Ortiz, 2011), which is currently under-utilized. Here we employ visible derivative spectroscopy with quotient normalization, varimax-rotated principal component analysis (VPCA) and kriging to understand the surface sedimentary processes of this study location.

In addition to clay mineralogy, visible derivative spectroscopy is capable of identifying other sediment components including iron oxides/oxyhydroxides, silica (from diatoms) and carbonate. Carbonate and silica are important because they provide additional constraints to primary productivity and the driving mechanisms of productivity. Future research on paleoflow, paleo-transgression and paleo-regression, and paleo-climate reconstruction is feasible using the clays and biogenic components, e.g., silica and carbonates.

2. Study locations and geological provinces

The Bering Sea shelf is a neritic zone (0–200 m bathymetry; National Research Council, 1996; Takahashi, 2005), and has a very gentile gradient (0.24–0.25 m/km); among the gentlest in the world (Gardner et al., 1980; Moser and Hein, 1984; National Research Council, 1996). The Bering Sea comprises a continental shelf with seven of the largest canyons in the world (Naidu et al., 1996; National Research Council, 1996). These canyons, from south to north are the Bering, Pribilof, Zhemchug, Middle, St. Mathew, Pervenets and Navarinsky canyons (National Research Council, 1996; Fig. 1). These canyons serve as a thoroughfare for shelf edge sediment to basin transport (Naidu et al., 1996). During winter, sea ice covers much of the shelf (National Research Council, 1996), and the whole shelf is ice-free during the summer (National Research Council, 1996; Stabeno et al., 1999). The Siberian shelf comprises one third of the Alaskan coast (Holmes, 1975; Viscosi-Shirley et al., 2003b). Ice covers most of the Siberian shelf nine months of the year, from September to May (Barnett, 1991; Viscosi-Shirley et al., 2003a). The marginal seas account for 86% of seasonal sea ice variability over the shallow shelf region of the west Arctic study locations (Stein, 2008). The western Arctic study region is covered by sea ice over the winter, while it is mostly ice-free over the summer (Stein, 2008).

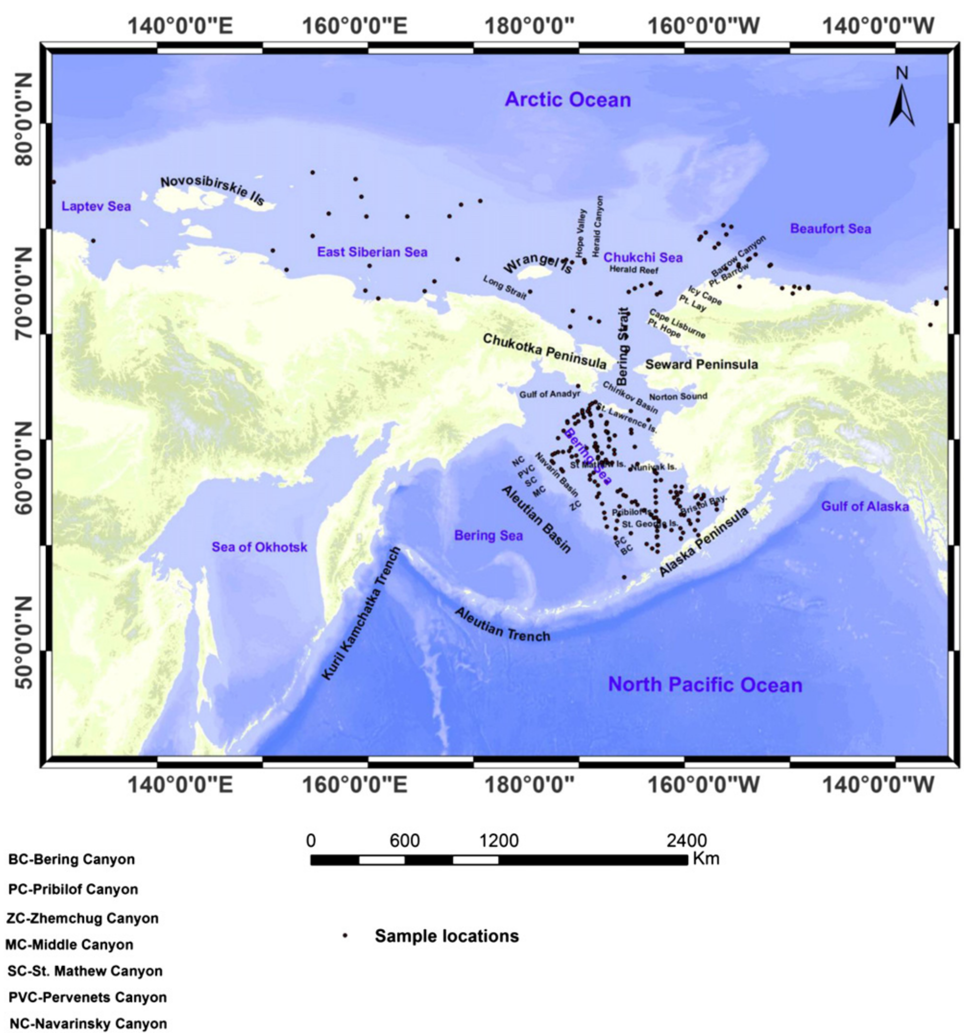

Fig. 1. Study location and core distribution.