JOURNAL OF ENVIRONMENTAL SCIENCES 52 (2017) 66–75

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JES JOURNAL OF ENVIRONMENTAL SCIENCES

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Sources and distribution of sedimentary organic matter along the northern Bering and Chukchi Seas

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ARTICLE INFO

Article history:
Received 7 December 2015
Revised 6 April 2016
Accepted 7 April 2016
Available online 27 April 2016

Keywords:
Lignin-derived phenols
Northern Bering Sea
Chukchi Sea

ABSTRACT

In this study, lignin-derived phenols were used to determine the sources and distribution of sedimentary organic matter along the northern Bering Sea and Chukchi Sea of the Arctic Ocean. The lignin parameter syringyl/vanillyl (S/V) and cinnamyl/vanillyl (C/V) ratios are used to indicate vegetation sources; and the ratios of vanillic acid/vanillin, (Ad/Al)v and syringic acid/syringaldehyde, (Ad/Al)s are used as indicators of lignin diagenesis. Results showed the predominance of woody gymnosperm signal at the easternmost location in the northern Bering Sea, a mixture of refractory non-woody angiosperm and fresher gymnosperm tissues in the Chukchi Sea, and signal of fresher woody gymnosperm tissues in the northernmost locations in the Chukchi Sea. The lignin materials showed gradual increase in decomposition stage during transport along the northern Bering Sea. Hydrodynamic sorting process, which is the retention of coarser materials nearshore and transportation of finer particles farther offshore, most probably occurred along the east coast of the northern Bering Sea. In Chukchi Sea, the non-woody angiosperm tissues could have originated from the Canadian Arctic and gymnosperm tissues could be from the Russian Arctic side. The fresher materials in the northernmost Chukchi Sea could have been transported here *via* the ice-rafting process. Detection of fresh lignin materials and the occurrence of lignin decomposition mean that this region could be sensitive to the impact of climate change.

Introduction

Regions of the Arctic Ocean have a strong land–ocean connection (Schubert and Calvert, 2001), as they have approximately 52.9% continental shelves whereas other oceans in the world have approximately 9.1% to 19.7% continental shelf regions (Jakobsson, 2002). Hence, the Arctic Ocean is very much affected by sediment discharge (Syvitski, 2003). Increasing snow melt has resulted in a steady increase in river discharge into the Arctic Ocean (Peterson et al., 2002; Syvitski, 2002) and human activities such as building of reservoirs and deforestation have changed the sediment discharge patterns (Bobrovitskaya et al., 2003). A steady decline of the Arctic ice cover (Comiso, 2006; Serreze et al., 2007; Stroeve et al., 2007; Arrigo et al., 2008; Comiso et al., 2008; Maslanik et al., 2011) has prolonged the growing season for phytoplankton, increased primary production (Arrigo et al., 2008) and caused massive under-ice phytoplankton bloom in the Chukchi Sea (Arrigo et al., 2012; Palmer et al., 2014). The Bering Sea has a colder and dryer northern portion and a warmer and more

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http://dx.doi.org/10.1016/j.jes.2016.04.003
1001-0742

humid southern portion and is therefore a transition zone between Arctic and sub-Arctic systems (Overland and Stabeno, 2004). Some changes in this region include increased air (Wang et al., 2012) and mean water temperatures (Overland and Stabeno, 2004). The northern Bering Sea is changing to a sub-arctic zone (Grebmeier et al., 2006), and Arctic species have been replaced by sub-Arctic species, causing huge economic losses in terms of the fishing industries. For instance, some fish species have decreased, but others have shown increase in abundance; and the feeding ground of walrus, gray whale and salmon has shifted northward. In short, the Arctic Ocean is a sensitive system which could serve as a good indicator of global climate change (Overland and Stabeno, 2004), hence, the reason to study this region.

Suites of biomarkers have been used to study the biogeochemistry of the Arctic Ocean, for example, the determination of amino acids and lignin in some Arctic rivers (Dittmar and Kattner, 2003; Amon et al., 2012) and studies of lipids in the western Fram Strait and the Yermak Plateau (Birgel et al., 2004). Glycerol dialkyl glycerol tetraethers (GDGTs) were used to determine past climate changes at the Mendeleev Ridge (Yamamoto and Polyak, 2009) and lipids and lignin were used to study past changes in the permafrost peat plateau of the Russian Arctic (Routh et al., 2014). Biomarkers have also been used to study the sources, distribution and fate of sedimentary organic matter, for example, lignin in the Mackenzie River Delta to the Beaufort Shelf (Goñi et al., 2000), lipids along the Chukchi (Belicka et al., 2002) and Beaufort Shelves (Belicka et al., 2009), and lignin in the regions spanning the North America Arctic margin (Goñi et al., 2013) and along the Siberian permafrost area and the East Siberian Arctic Shelf (Tesi et al., 2014; Bröder et al., 2016). The present study aimed to determine the sources and distribution of sedimentary organic matter along the northern Bering and Chukchi Seas, as this transect represents an important route of water from the Pacific Ocean flowing into the Arctic Ocean. We hypothesize that the sedimentary organic matter reflects the vegetation of the adjacent surrounding areas and we are interested to determine the fate of sedimentary organic matter during transport along this route.

In this study, lignin is used as a biomarker to determine the sources and distribution of terrigenous organic matter. Because angiosperm plants produce vanillyl (V) and syringyl (S) phenols and gymnosperm plants yield only vanillyl phenols, S/V ratios >0 are indicative of angiosperm tissues, and S/V = 0 represents gymnosperm tissues. As only non-woody vascular plants produce cinnamyl phenols (C), C/V ratios >0 indicate the presence of non-woody tissues, and C/V = 0 represents woody tissues (Hedges and Mann, 1979; Kuzyk et al., 2008). Lower S/V ratios indicate the dominance of gymnosperm or taiga vegetation, and higher S/V ratios represent non-woody angiosperm of tundra in the Arctic Ocean (Dittmar and Kattner, 2003). The vanillic acid/vanillin and syringic acid/syringaldehyde ratios are abbreviated as (Ad/Al)v and (Ad/Al)s. The (Ad/Al)v and (Ad/Al)s values for fresh plant materials range from 0.10 to 0.20, and higher values indicate more elevated degradation stage of lignin materials (Hedges and Mann, 1979). Total lignin is the sum of V, S and C phenols and is known as Λ (mg/100 mg organic carbon (OC)).

1. Study area: Bering and Chukchi Seas

The Bering Sea is situated off the northern Pacific Ocean (Fig. 1). The fresher inflowing water from the Pacific and river runoff results in the formation of stratification in the Arctic Ocean (Naidu et al., 2000). The northern Bering and Chukchi Seas are seasonally ice-covered for approximately seven months (Grebmeier et al., 1988). The Bering Sea enters the Chukchi Sea, which is approximately 500 km wide and 800 km long, during spring and early summer *via* the narrow 80 km long Bering Strait (Viscosi-Shirley et al., 2003; Weingartner et al., 2005; Woodgate et al., 2005; Grebmeier et al., 2006; Hunt et al., 2013). The three distinctive water masses in the Bering Sea are the Anadyr Water on the west, the Bering Shelf Water in the middle and the Alaskan Coastal Water on the east. The Anadyr Water is more

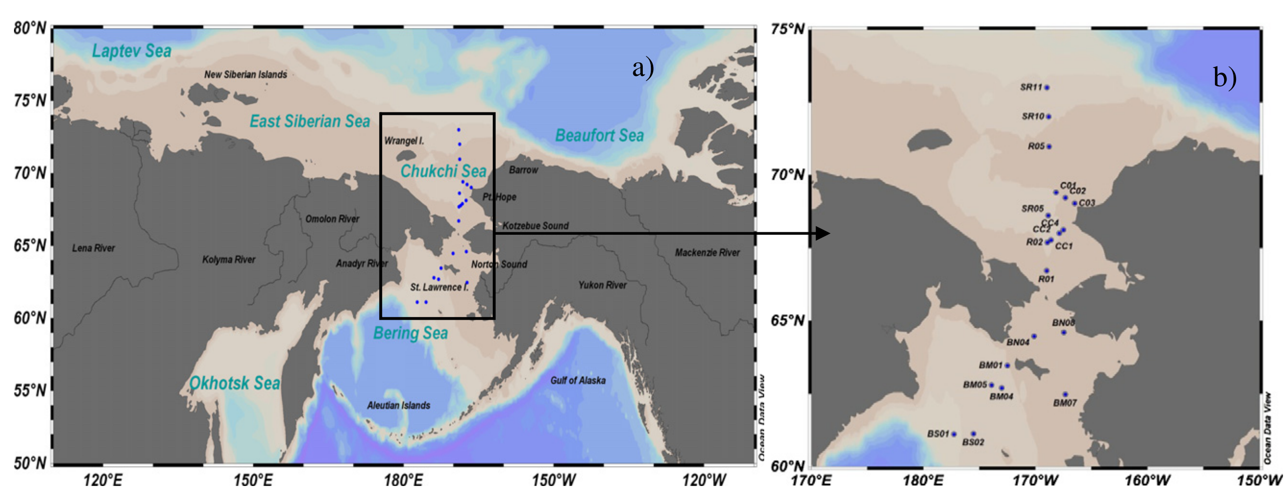

Fig. 1 – Map showing the sampling locations along the northern Bering Sea, Bering Strait and Chukchi Sea, with (a) outline of the major rivers draining into the Arctic Ocean and northern Bering Sea, and (b) our sampling locations magnified.