Deep-Sea Research II 125-126 (2016) 1–7

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Introduction

Introduction to Pliocene–Pleistocene paleoceanography of the Bering Sea

ARTICLE INFO

Keywords:
Paleoceanography
IODP Expedition 323
Sea-ice
Diatoms
Silicoflagellates
Oxygen minimum zone
Bowers Ridge
Bering Slope

ABSTRACT

High resolution paleoceanography of the Pliocene–Pleistocene is important in understanding climate forcing mechanisms and associated environmental changes during this major transition from global warmth to the Ice Ages. This is particularly true in high latitude marginal seas such as the Bering Sea. The Bering Sea has been very sensitive to changes in global climate during interglacial and glacial, or Milankovitch, time scales. This is due to significant changes in water circulation, land–ocean interaction, and sea-ice formation. With the aim to reveal the climate and oceanographic history of the Bering Sea over the past 5 My, IODP Expedition 323 cored a total of 5741 m of sediment (97.4% recovery) at seven sites in 2009 on D/V JOIDES Resolution covering three regions: the Umnak Plateau, the Bowers Ridge, and the Bering Slope. The water depths of the drill sites range from 818 m to 3174 m, allowing for the characterization of past vertical water mass distribution including changes in the oxygen minimum zone. The four deepest holes range from 600 m to 745 m below the seafloor, and resulted in the recovery of long sediment sequences ranging from 1.9 My to 5 My in age. Following the expedition, two sampling parties at Kochi Core Center (for acquisition of ca. 58,000 subsamples) and two scientific meetings were conducted in order to proceed with the analyses of sediment core samples and discussions. Here, pertinent results, primarily from IODP Expedition 323, are consolidated as a single special volume of Deep-Sea Research Part II Topical Studies in Oceanography.

1. Introduction

The rate and regional expression of recent global warming is difficult to understand and even more difficult to predict because of the complex nature of the climate system, whose components interact nonlinearly with various time lags and on various timescales. Paleoclimatic and paleoceanographic studies provide opportunities to study the dynamics of the climate system by examining how it responds to external forcing (e.g., greenhouse gas and solar radiation changes) and how it generates internal variability due to interacting Earth-system processes. Of note is the amplified recent warming of the high latitudes in the Northern Hemisphere (Solomon et al., 2007), which is presumably related to sea-ice albedo feedbacks and teleconnections to other regions; both the behavior of sea-ice–climate interactions and the role of large-scale atmospheric and oceanic circulation in climate change can be studied with geologic records of past climate changes in the Bering Sea (Takahashi et al., 2011a).

Global climate during the Pliocene through Pleistocene includes the following: the early Pliocene warm period (~5–3 Ma) in which the mean global temperature was ~3 °C warmer than today (Haywood and Valdes, 2004); the onset of significant Northern Hemisphere glaciation (NHG), which began gradually as early as 3.5 Ma (Mudelsee and Raymo, 2005) and was well-developed by 2.6–2.7 Ma in the North Pacific (Krissek, 1995); the gradual cooling of upwelling zones (Dekens et al., 2007; Brierley et al., 2009); and establishment of strong Walker Circulation in the tropical Pacific (Wara et al., 2005) by ~1.8 Ma; and the transition from 41-kyr to 100-kyr glacial–interglacial cycles between 1.25 and 0.7 Ma, referred to as the Mid-Pleistocene Transition (MPT) (Clark et al., 2006).

Prior to 2009, little was known about the sedimentology and climate history of the Bering Sea outside of a few piston core studies (e.g., Cook et al., 2005; Okazaki et al., 2005; Katsuki and Takahashi, 2005; Tanaka and Takahashi, 2005; Takahashi, 2005) and Sites 188 and 185 (Scholl and Creager, 1973), which were drilled by the Deep Sea Drilling Project (DSDP) in 1971 with old drilling technology and poor recovery. Past studies using piston cores in the Bering Sea indicated that, while current conditions in the Bering Sea promote seasonal sea-ice formation, during the Last Glacial Maximum (LGM) conditions sustained perennial or nearly perennial sea-ice cover (Tanaka and Takahashi, 2005), attesting to the potential utility of sedimentary records in the Bering Sea to examine past sea-ice distributions. In paleoceanographic studies of the North Pacific, the Bering and Okhotsk seas have been implicated as a source of dense oxygenated intermediate water that possibly impacted oceanic and climate conditions throughout the Pacific on glacial–interglacial (e.g., Gorbarenko, 1996; Matsumoto et al., 2002) and millennial (e.g., Hendy and Kennett, 2003; Ono et al., 2005) timescales. In addition, changes in Bering Sea

http://dx.doi.org/10.1016/j.dsr2.2016.03.001
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environmental conditions could be related to sea level and circulation changes, which alter flow patterns through narrow straits that connect the Bering Sea to the Arctic Ocean to the north and the Pacific Ocean to the south (Fig. 1). The lack of pertinent Bering Sea material had prevented the evaluation of these and other ideas for a long time.

2. Planning and objectives of drilling and coring

A drilling expedition to the Bering Sea, under the umbrella of Ocean Drilling Program (ODP) and Integrated Ocean Drilling Program (IODP), was planned initially in 1995 to achieve the following objectives (Takahashi et al., 2009a). The study of the sedimentary records from the Bering Sea would provide an understanding of: (1) The evolution of Pliocene–Pleistocene surface water conditions, paleoproductivity, and sea-ice coverage, including millennial to Milankovitch scale oscillations; (2) The history of past production of the Pacific Intermediate and/or deep water masses within the marginal sea, and its link to surface water processes; (3) The interactions between marginal sea conditions and continental climate; (4) The linkages between processes in the marginal sea (e.g., variations in deep water formation, or water mass exchange through gateways) and changes in the pelagic Pacific; (5) An evaluation of how the history of ocean/climate of the Bering Strait gateway region may have had an effect on north Pacific and global conditions; and (6) Constraints of global models of subseafloor biomass and microbial respiration by quantifying subseafloor cell abundance and pore water chemistry in an extremely high productivity region of the ocean. All of these scientific objectives would focus both on the long-term ocean and climate trends, as well as the evolution of higher frequency glacial–interglacial to millennial scale oscillations through the Pliocene–Pleistocene.

3. Results

3.1. Drilling strategy of IODP Expedition 323 to the Bering Sea

In the summer of 2009, after 14 years of continuous preparation including a site survey cruise in 1999 since the original conception of the drill plan, IODP Expedition 323 was carried out in the Bering Sea. The expedition successfully collected 660 sediment cores, mostly high quality advanced piston cores, spanning 5741 m in total length with 97.4% recovery. The cores are from seven drill sites distributed in the Bering Sea to constrain past changes in Bering Sea conditions including sea-ice distribution. The seven drilled sites include the following three topographic highs in order to capture hemipelagic and terrestrial signals: the Bowers Ridge (U1340, U1341 and U1342), the Umnak Plateau (U1339), and the Bering Slope (U1343, U1344 and U1345) (Table 1, Figs. 2, and 3). Furthermore, the approach of drilling a depth transect was adopted in order to capture different chemistry signals for calcium carbonate dissolution as well as oxygen levels (Fig. 4). The Bowers Ridge sites provide climate records that span the last 5 million years, and the Bering Slope records span the last 2.4 million years (Table 1; Takahashi et al., 2011a,b).

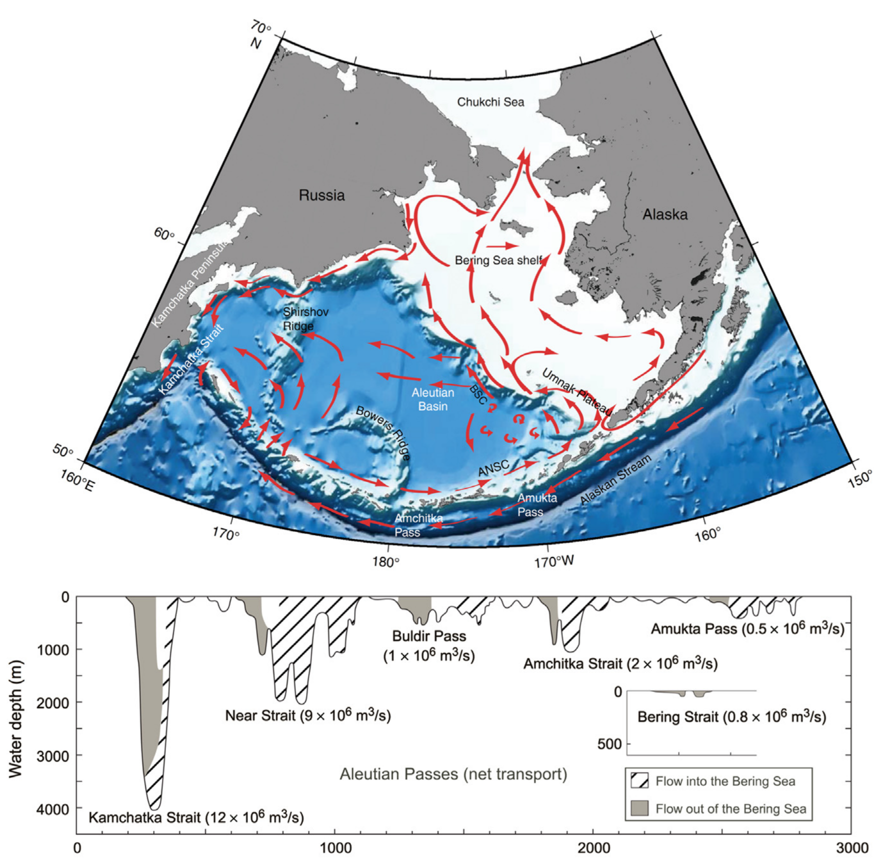

Fig. 1. Map showing the modern surface water circulation in the Bering Sea, along with cross sections of the Aleutian passes with volume transport (Sv) (Stabeno et al., 1999) and the Bering Strait (Takahashi et al., 2011b).