Pleistocene deep sea ostracods from the Bering Sea (IODP Expedition 323)

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Abstract

The study presents the first Pleistocene (0-1.9 Ma) record of deep sea ostracods from the Bering Sea, derived primarily from Integrated Ocean Drilling Program Expedition 323, Site U1344 (59°3.0'N, 179°12.2'W, 3171 m of water depth). Deep sea ostracod abundances in the Bering Sea sediments are some of the lowest that have been recorded in bathyal marine environments (<1 specimen per sediment gram). In comparison, benthic foraminifera are several orders of magnitude more abundant in the same samples. The humble ostracod assemblage at Site U1344 is predominantly composed of deep water species *Krithe sawanensis*, *Fallacihowellia* sp. A, *Cytheropteron* spp., *Eucytherura* sp., *Argilloecia toyamaensis*, and *Bradleya mesembrina*. Less abundant taxa include *Munseyella melzeri*, *Munseyella ristveti*, *Cluthia* sp., *Robertsonites hanaii*, and *Microcythere mediotriata*. Some of these taxa (e.g. *Fallacihowellia* sp. A, *Bradleya mesembrina*, *Microcythere mediotriata*) are reported for the first time in the North Pacific. The predominance of the genera *Krithe*, *Fallacihowellia*, *Cytheropteron* and *Argilloecia* indicates cold, ventilated bottom waters. The deep Bering Sea ostracod assemblage shares many common and closely related species with slope faunas from the Gulf of Alaska, the Okhotsk Sea, the Arctic Ocean, and even the subpolar North Atlantic. A few continental shelf ostracods, such as species of *Munseyella* and *Robertsonites*, are present at Sites U1344 and U1343, in the northern slope of the Aleutian Basin. The presence of shallow water ostracods at the Bering Sea slope

24 sites is possibly explained by sea ice rafting. Exceptionally low ostracod abundance in the U1344
25 record did not permit evaluating links between ostracod faunas and paleoceanographic
26 conditions; however, an increase in ostracod occurrences throughout the middle Pleistocene at
27 Site U1344 appears to correlate with general sea ice expansion in the Bering Sea. High primary
28 surface productivity, high food flux and high sedimentation rates are considered to be the main
29 factors diluting or suppressing deep sea ostracods in the Bering Sea, suggesting that ostracods
30 may prefer living in more oligotrophic deep water environments with well oxygenated waters
31 and moderate food supply.

1. Introduction

The majority of the ostracod studies from high latitude North Pacific marginal seas have focused on Miocene to Pleistocene sequences in and around Japan, the Japan Sea (e.g., Okada, 1979; Cronin and Ikeya, 1987; Ikeya et al., 1992; Ikeya and Cronin, 1993; Ozawa, 2003; Ozawa et al., 2004; Ozawa and Kamiya, 2005; Ozawa, 2009; Irizuki et al., 2007, 2009; Iwatani et al., 2012; Yamada et al., 2002), modern sediments in the Okhotsk Sea (Ozawa, 2004; Ozawa and Tsukawaki, 2008), and Quaternary sediments in the Gulf of Alaska (Brouwers, 1988, 1990, 1993, 1994). Yet, with the exception of a recent study of modern benthic ostracods from the northern Bering and Chukchi Sea shelves (Gemery et al., 2013), very little is known about ostracods from the Bering Sea, in particular bathyal and abyssal faunas. One potential reason for the lack of information on deep sea ostracods from this region is their very low abundance in biosiliceous-rich sediments that characterize the North Pacific Ocean. Sediment in the deep Bering Sea generally lacks abundant carbonate microfossils because the seafloor is below the carbonate compensation depth (CCD) in most regions. The lysocline and the CCD over the continental slope of the Bering Sea are documented at depths of 2000 and 3800 m, respectively (Chen et al., 2005). This study uses core samples derived from sites drilled during Integrated Ocean Drilling Program (IODP) Expedition 323 to examine and document the abundance, taxonomic composition, and paleoenvironmental significance of deep sea ostracod assemblages from the Bering Sea.

IODP Expedition 323 sailed into the Bering Sea in 2009 with the aim at studying for the first time the sedimentary and paleoceanographic history of this marginal sea over the past 5 Ma. Seven sites (U1339 to U1345) distributed on a depth transect ranging from 819 to 3173 and

covering three different regions (Umnak Plateau, Bowers Ridge, and the Bering slope region) were successfully drilled during the expedition (Figure 1, Table 1)(Takahashi et al., 2011).

The cored sedimentary sequences at the Bering Sea sites are composed of terrigenous, glaciomarine, and biogenic components that capture the spatial and temporal evolution of the Bering Sea through the Pliocene and Pleistocene (Takahashi et al, 2011). Terrigenous sediment are mostly made up of angular siliciclastics and volcanoclastics, whereas biogenic sediment predominantly contain siliceous microfossils (diatoms, radiolarians, silicoflagellates, ebridians), and a much lower amount of organic (dinoflagellates), and calcareous microfossils (nannofossils, planktonic and benthic foraminifers, and ostracods) (Takahashi et al, 2011).

2. Study area

The Bering Sea is the third largest marginal sea in the world and one of the world's most productive regions, supporting high seasonal primary productivity exceeding $1\text{gC m}^{-2}\text{ d}^{-1}$ during the spring bloom (Brown et al., 2011; Springer et al., 1996), and exhibiting sediment with profuse siliceous microfossils, and very high sedimentation rates (Takahashi et al., 2011; Aiello and Ravelo, 2012). Approximately one half of the Bering Sea is a shallow (0–200 m) neritic environment, with the majority of the continental shelf spanning the eastern side of the basin off Alaska from Bristol Bay to the Bering Strait (Figure 1). The northern continental shelf is seasonally ice covered, and little ice forms over the deep southwest areas. In addition to the shelf regions, two significant topographic highs have better carbonate preservation than the deep basins: Shirshov Ridge, which extends south of the Koryak Range in eastern Siberia; and Bowers Ridge, which extends 300 km northwest from the Aleutian Island arc. To the south of the Bering

Sea is the Aleutian Basin, a vast plain ~3850 m deep, with occasional gradually sloping depressions as deep as 4150 m (Hood, 1983).

Three major rivers flow into the Bering Sea: the Kuskokwim and Yukon rivers drain central Alaska, and the Anadyr River drains parts of eastern Siberia. Surface water circulation in the Bering Sea is dominated by an anticlockwise gyre (the Bering Sea Gyre) along the Bering Slope, contributing to the main flow of the Bering Slope Current (BSC, Stabeno et al., 1999). Water exchange between the Bering Sea and the North Pacific Ocean takes place along the several paths between the Aleutian Islands (generally between 1 and 4 km water depth).

3. Materials and Methods

3.1. Site U1344

This study focuses on IODP Site U1344 in the center of the northern Bering Sea slope margin, but also examines selected samples from Sites U1339, U1341, U1342, and U1343 (Figure 1, Table 1). Site U1344 (59°3.0'N, 179°12.2'W, 3171 m of water depth) is located on a small summit of a canyon interfluve and ~10-15 km southeast of Pervenets Canyon, a large submarine canyon that deeply, and widely incises the Beringian continental slope. During glacial times and low sea level, the head of Pervenets Canyon is believed to have been one of the outfall locations for the Anadyr River, which presently drains the Russian northeast and enters the Bering Sea at the Gulf of Anadyr. Site U1344 is situated in an area of very high biological surface productivity, high organic carbon accumulation at the seafloor (Springer et al., 1996), and close to the maximum extent of present day seasonal sea ice cover (Takahashi et al., 2011).

Five holes were cored at Site U1344 to various depths below seafloor (Takahashi et al., 2011). Core samples examined in this study are primarily from Hole U1344A, the deepest hole, which extends from the seafloor down to 746.6 mbsf (meters below the seafloor). Based on shipboard biostratigraphic and magnetostratigraphic data, the cored section in Hole U1344A covers the past ~1.9 million years (Takahashi et al., 2011). The sample resolution for the present study averages 4.6 m (or ~11.7 ky) throughout the section.

3.2. Other sites

Site U1339 is situated on the Umnak Plateau off Bristol Bay in the eastern Bering Sea at 1868 m of water depth (Figure 1, Table 1). Today, parts of the relatively warm Alaskan Stream surface water flow into the Bering Sea through the Umnak and Amukta passes in the Aleutian Islands, and hence sea ice is not formed in this region. However, substantial sea ice coverage during the Last Glacial Maximum (LGM), when sea level was 125-130 m lower than today, has been inferred (Cook et al., 2005; Caissie et al., 2010). Because the eastern passes are fairly shallow (~50 and 430 m), little intermediate or deep water exchange occurs with the North Pacific Ocean in this region (Tanaka and Takahashi, 2005). Site U1342 is situated at a relatively shallow water depth (818 m) on the Bowers Ridge, in the southern Bering Sea. Site U1343 is located on a topographic high (1953 m) on the northern slope, close to U1344, and separated from the Bering shelf (Takahashi et al., 2011). At U1339, the study focuses on an interval from 66.4 to 84.5 mbsf where samples were previously examined for benthic foraminifera. At the other sites, I re-examined ostracod specimens picked during routine shipboard examination for benthic foraminifera but that were left in open nomenclature in the Expedition Reports (Takahashi et al., 2011).

Mudline samples taken from the uppermost core at selected boreholes at each site during Expedition 323 were also examined for the presence of ostracods. These samples are different from ordinary coretop samples in that they represent the soft and fluffy sediment at the sediment/water interface. Mudline samples were dyed with Rose Bengal soon after core recovery, and allowed soaking for 24 hours before sieving and drying. The size and successful recovery of mudline samples varied from hole to hole and from site to site as a result of the coring process, hole-to-hole stratigraphic correlation strategies, and sediment type.

3.3. Age models

Biostratigraphic datums and magnetostratigraphic data (chron ages) obtained during shipboard analyses on Expedition 323 provide the chronostratigraphic framework for the drill sites (Takahashi et al., 2011). Based on a linear interpolation of these data at Site U1344, sediment accumulation rates ranging from ~30 to 90 cm/ky (average of ~45cm/ky) were estimated. A summary of the coring results, ages and sedimentation rates for all the sites is shown in Table 1.

3.4. Analytical methods

Bulk samples with an individual initial volume of 34 cc (a 2 cm half-round core sample) were dried and weighed, and later washed with tap water over a 63 μm sieve. Once dry, the coarse fractions ($> 63 \mu\text{m}$) were weighed before picking. All ostracods were picked from the $>125 \mu\text{m}$ sediment size fractions with a fine, damp brush under a light microscope and placed on

slides, where they were identified and counted. While single valves were counted as one specimen, complete carapaces were enumerated as two valves. For ostracod identifications, I followed the taxonomy provided in Brouwers (1990, 1993, 1994), Ozawa and Tsukawaki (2008), and other ostracod works from the Okhotsk Sea and the North Pacific. Taxonomic nomenclature follows the World Ostracod Database (Brandão et al., 2014). Selected specimens were coated using standard Pd-Au coating techniques, and digitally imaged using an FEI Quanta 600 FE scanning electron microscope.

3. Results and Discussion

A total of twenty one taxa were identified from one hundred and eighty two core samples from Site U1344, eighty nine core samples from Site U1339, and mudline samples from Sites U1339, U1342, U1343 and U1344. Among all of these samples, only 44 contained ostracods. In addition, all ostracods picked from core catcher samples during Expedition 323 were re-examined and their taxonomy revised. The overall assemblage includes a mixture of mainly upper and lower slope species (Table 2). Representative taxa are illustrated in Plates 1 and 2.

Absolute ostracod abundance was very low, four specimens per sample or less (<1 specimen per sediment gram) at all sites. The exceptionally low and sporadic ostracod density in the Bering Sea samples, in particular in the long record at Site U1344 (Figure 2), prevented any reliable statistical analyses of the data and any potential linking of the ostracod faunas to paleoceanographic conditions or climatic periods (e.g., glacial or interglacial periods). Despite the low abundance, ostracod preservation was generally good (translucid valves), and about half of the specimens found are articulated carapaces. Poorly preserved specimens were few and they

exhibited white to yellowish valves, and showed some signs of dissolution or recrystallization. Dark yellow specimens were generally observed in the older (>1.2 Ma) part of Site U1344 record.

3.1. Ostracod assemblage composition

The most common genera in the Bering Sea samples are *Krithe*, *Fallacihowellia*, *Cytheropteron* and *Argilloecia*. These taxa are known to prefer cold and well ventilated bottom waters, and moderate to ample food supply (Didié et al., 2002; Ayress et al., 2004; Mazzini, 2005; Alvarez Zarikian et al., 2009; Poirier et al., 2012, Yasuhara et al., 2012). They all have global distribution and are found in all the world oceans. In the central Arctic Ocean, *Krithe* and *Cytheropteron* have been associated with the interglacial conditions, and possibly deep water convection as is found in the Norwegian-Greenland Sea (Poirier et al., 2012; Cronin et al., 2013). In the North Atlantic, *Cytheropteron* is associated with deglacial transitions and fresh food supply. *Argilloecia* and *Henryhowella* (a related genus of *Fallacihowellia*) are associated with interglacials and interstadials (Cronin et al., 1999; Alvarez Zarikian et al., 2009). In the South Atlantic sector of the Southern Ocean, *Krithe* was highly abundant during interglacials MIS 1 and 5 and was almost absent during glacials MIS 2–4, while *Henryhowella* was dominant during the glacial MIS 2–4 and was less abundant during the interglacial MIS 1 and 5 (Yasuhara et al., 2009). These two genera do not co-occur in the same samples in the Bering Sea, but ostracods are so rare in the deep Bering Sea that it is not possible to establish any paleoenvironmental patterns.

The ostracod assemblage at Site U1344 includes *Krithe sawanensis* Hanai, *Fallacihowellia* sp. A, *Eucytherura* sp., *Cytheropteron hanaii* Ishizaki, *Cytheropteron* spp.,

184 *Argilloecia toyamaensis* Ishizaki and Irizuki, *Bradleya mesembrina* Mazzini, *Munseyella melzeri*
185 Brouwers, *Cluthia* sp., *Microcythere mediotriata* (Joy and Clark), *Polycope* sp. and
186 *Loxoconchidea* sp. The ostracod assemblage at Site U1339 has a similar taxonomic composition
187 with additional species of *Cytheropteron* (Tables 2 and 3).

188 The U1344 data illustrated in Figure 2 show that most samples were barren of ostracods
189 during the early and middle Pleistocene (~1.9 to 0.6 Ma). Ostracod densities slightly increase
190 during the Late Pleistocene. The slight increase in ostracod peaks at the end of the mid-
191 Pleistocene seems to be synchronous with an increase in cold water and sea ice related diatom
192 species observed at nearby Site U1343 (Teraishi et al., 2014).

193 Mudline samples also yielded very low ostracod abundances. However, most of the
194 modern specimens represented articulated carapaces, and several of them were stained with Rose
195 Bengal. Stained individuals are considered to have been alive at the time of sampling. Live
196 specimens included *Cytheropteron* sp. C (Site U1343) and *Cytheropteron* sp. A (Site U1344).
197 Non-stained specimens of *Cytheropteron* sp. A and *Loxoconchidea* sp. were observed in the
198 U1342 mudsample (Bowers Ridge), while *Munseyella melzeri*, *Munseyella ristveti* and
199 *Robertsonites hanaii* were found in core samples from Site U1343.

200 The Bering Sea ostracod faunas share many common and closely related species with
201 slope faunas from the Gulf of Alaska, the Okhotsk Sea, the Arctic Ocean, and the subpolar North
202 Atlantic. The strong affinity among these faunas is reasonable given the adjacent nature of these
203 marginal seas, slopes and shelves, and the depth connections through the Umnak and Amukta
204 passes in the Aleutian Islands to the east, the Strait of Kamchatka to the west, and the Arctic
205 gateway to the north.

The presence of a few shallow water (shelf to upper slope) taxa, such as *Munseyella* and *Robertsonites* (Ozawa, 2004), at Sites U1343 and U1344 can be explained by sea ice rafting, which is a well-known mechanism for the distribution of ostracods in high latitude areas, such as the Arctic and North Atlantic (Didié and Bauch, 2000; Stepanova et al., 2003; Alvarez Zarikian et al., 2009) and the Okhotsk Sea (Ozawa, 2004). The presence of ice rafted ostracods at Sites U1343 and U1344 is not surprising because these sites are located along the northern Bering Sea slope, proximal to the maximum extent of the modern seasonal sea ice cover, and under an area of high biological productivity and high sedimentation rates (Springer et al., 1996; Takahashi et al., 2011). During glacial times, sea ice expanded further southward onto the Bering Sea basin. Grain size analysis on the sediments from Site U1343 and U1344, suggested that the clay sized particles at the Bering Sea Slope were delivered mainly from sedimentation processes via ice-rafting (Aiello and Ravelo, 2012). Moreover, higher sedimentation rates at the Bering Sea Slope sites than at the other Expedition 323 sites was attributed to greater contribution of siliciclastic components to the Bering Sea Slope (Takahashi et al., 2011).

3.2. Ostracod abundance in the Bering Sea

Ostracod distribution in the deep sea is primarily controlled by food supply, sediment accumulation rates, and bottom water ventilation (Dingle and Lord, 1990; Corrège, 1993; Ayress et al., 1997; Didié et al., 2002; Ozawa, 2004; Yasuhara and Cronin, 2008; Yasuhara et al., 2009; Alvarez Zarikian, 2013). In eutrophic environments, such as the Bering Sea, critical oxygen levels in the bottom waters can be a major limiting factor for benthic faunal density and diversity (Jorissen et al., 2007), although some organisms, such as some benthic foraminifers, are able to tolerate and even thrive in dysaerobic conditions and take advantage of the ample food supply more effectively than ostracods (Yasuhara et al., 2012). In the Bering Sea samples, calcareous

benthic foraminifer abundances are typically orders of magnitude higher than ostracods (as many as ~300 to ≤ 1). The exceptionally low ostracod abundance is surprising because the calcareous shells of ostracods and foraminifera exhibit similar size ranges and are usually abundantly preserved in marine sediments. Both groups of organisms are believed to exploit the same food source in the deep sea particulate organic matter that sinks from shallower depths (Gooday, 1994; Didié and Bauch, 2000; Cronin and Dwyer, 2003; Yasuhara and Cronin, 2008; Yasuhara et al., 2012).

Site U1344 lies today below the modern oxygen minimum zone (Takahashi et al., 2011), and the ostracod assemblage composition at Site U1344 suggests that the bottom waters at this site are moderately well ventilated. Therefore, it is hypothesized that in the Bering Sea, low ostracod abundance cannot be explained by poor bottom water ventilation alone, but by a combination of other environmental factors. High primary surface productivity and high sedimentation rates of particulate organic matter, diatom frustules, and siliciclastic and volcanoclastic material could be the primary reasons for the low ostracod densities in the deep Bering Sea. However, poor carbonate preservation due to dissolution cannot be discarded.

Low ostracod densities have been recorded at least at another high productivity region in the North Pacific. A recent study on the Shatsky Rise by Yasuhara et al. (2012) has shown that the abundance of benthic foraminifers has a positive relationship with both primary surface productivity and seasonality of productivity. In contrast, the same study showed that ostracod abundance has an inverse relationship at high productivity levels. The Bering Sea ostracod data support the results at the Shatsky Rise and indicate the existence of different responses to environmental factors between ostracods and benthic foraminifers. Comparison of the Bering Sea ostracod data with faunal data from the South Pacific Gyre (Alvarez Zarikian, 2013), one of

the most oligotrophic ocean regions in the world, indicates the preference of ostracods for habitats with moderate food supply and higher oxygen concentrations.

4. Conclusions

This study presents the first Pleistocene record of deep sea ostracods from the Bering Sea. Ostracod abundances in the Bering Sea sediments are some of the lowest recorded in bathyal marine environments (<1 specimen per sediment gram). In comparison, benthic foraminifera in the same samples are several orders of magnitude more abundant. The ostracod assemblage at Site U1344 is predominantly composed of deep water species *Krithe sawanensis*, *Fallacihowellia* sp. A, *Cytheropteron* spp., *Eucytherura* sp., *Argilloecia toyamaensis*, and *Bradleya mesembrina*. Minor taxa include *Munseyella melzeri*, *Cluthia* sp., *Robertsonites* sp., and *Microcythere mediotriata*. Predominance of the genera *Krithe*, *Fallacihowellia*, *Cytheropteron* and *Argilloecia* indicates cold and oxygenated bottom waters. Pleistocene deep sea ostracods in the Bering Sea share many common and closely related species with slope faunas from the northern Japan Sea, the Okhotsk Sea, the Gulf of Alaska, the Arctic Ocean, and the subpolar North Atlantic. The occasional presence of typical shallow water ostracods, such as *Munseyella* and *Robertsonites*, at the Bering Sea slope Sites U1344 and U1343 can be explained by sea ice rafting, or may reflect the ability of ostracod species that live in cold water in high latitude seas to migrate and live in deeper waters at more southern high latitudes. No links between ostracod faunas and past oceanographic conditions during the Pleistocene and Holocene were recognized due to exceptionally low ostracod abundance at Site U1344. However, the onset of subtle ostracod peaks in the record coincides with times of sea ice expansion in the Bering Sea

from the middle to the late Pleistocene. Although carbonate dissolution is an important factor in the preservation of calcareous organisms in the Bering Sea, high primary surface productivity, high sedimentation rates and high food flux to the sea bed seem to be the main factors depressing deep sea ostracod densities at the studied sites. Comparison of the Bering Sea ostracod data with other ocean regions indicates that deep sea ostracods may prefer well oxygenated waters in more oligotrophic environments with moderate food supply.

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Table 1. Drilling results summary for Expedition 323 sites.

IODP Site	Coordinates	Water depth (m)	Penetration depth (m)	Age (Ma)	Average sedimentation rate (cm/ky)
Bering Slope					
U1344	59°03.00'N, 179°12.20'W	3171	745	0-1.9	45
U1343	55°33.39'N, 175°48.95'W	1950	744	0-2.4	31
Umnak Plateau					
U1339	54°40.20'N, 169°58.90'W	1868	200	0-0.8	28
Bowers Ridge					
U1340	53°24.00'N, 179°31.29'W	1294	604	0-5	12
U1341	54°24.00'N, 179°00.49'E	2139	600	0-4.3	14
U1342	54°49.70'N, 176°55.02'E	818	47.3	0-~1	3.6
IODP: Integrated Ocean Drilling Program. Shaded row highlights Site U1344.					

Table 2. List of ostracod taxa determined at the Bering Sea sites.

Ostracod taxa	Illustration in this paper	Reference
<i>Argilloecia toyamaensis</i> Ishizaki and Irizuki	Pl. 1, Figs. 11a-b	Ozawa (2004): pl.1, fig. 7
<i>Bradleya mesembrina</i>	Pl. 2, Fig. 2	Mazzini (2005): figs. 47A-K, 48B
<i>Cluthia</i> sp.	Pl. 1, Fig. 10	Yasuhara and Okahashi (in press): pl. 14, figs. G-H
<i>Cytheropteron</i> sp. A	Pl. 1, Figs. 1-2	Strongly resembles <i>C. massoni</i> Whatley and Coles [Whatley and Coles (1987): pl.2, figs. 15-17]; similar to <i>C. hanaii</i> Ishizaki [Ishizaki (1981): pl. 12, figs. 1-4, pl. 13, figs 8-9]
<i>Cytheropteron</i> sp. B	Pl. 1, Fig. 3	
<i>Cytheropteron</i> sp. C	Pl. 1, Fig. 4	Similar to <i>C. haydenensis</i> Brouwers (Brouwers, 1994)
<i>Cytheropteron</i> sp. D	Pl. 1, Fig. 5	
<i>Cytheropteron</i> sp. E	Pl. 1, Fig. 6	Similar to <i>Eucytherura pacifica</i> Ayress et al. (1995)
<i>Eucythere</i> sp.	n/a	
<i>Eucytherura</i> sp.	Pl. 2, Figs. 8a-c	
<i>Fallacihowellia</i> sp. A sensu Mazzini	Pl. 2, Fig. 1	Mazzini (2005): p. 56, fig. 31
<i>Hemicytherura</i> sp.	Pl. 2, Fig. 6	Ozawa et al. (2004): pl. 2, fig. 18. Ozawa and Kamiya (2005): pl. 1, fig. 5.
<i>Krithe sawanensis</i> Hanai	Pl. 1, Fig. 9a-b	
<i>Loxoconchidea</i> sp.	Pl. 2, Figs. 10a-b	Similar to <i>L. dolgoiensis</i> Brouwers: Brouwers (1993): pl. 15, figs. 4-16. Irizuki et al. (2007): p. 427, fig. 6.13.
<i>Microcythere mediotriata</i> (Joy and Clark)	Pl. 1, Fig. 7	Brouwers (1990): pl. 6, figs. 9-15; pl. 7, figs. 2, 3 Brouwers (1990): pl. 6, figs. 16-18; pl. 7, fig. 4
<i>Munseyella melzeri</i> Brouwers	Pl. 2, Fig. 3a-b	
<i>Munseyella ristveti</i> Brouwers	Pl. 2, Fig. 4	
<i>Palmoconcha</i> sp.	Pl. 2, Fig. 7	Yasuhara et al. (2009): pl. 4, figs. 7-12 Similar to <i>R. hanaii</i> Tabuki: Tabuki (1986): pl. 13, figs.1-12
<i>Polycopse</i> sp.	n/a	
<i>Pseudocythere caudata</i> Sars	Pl. 1, Fig. 8	
<i>Robertsonites</i> sp.	Pl. 2, Fig. 5	

Table 3. Ostracod range chart for Site U1344. Below: samples from other Expedition 323 sites where ostracods were found.

[illegible]

493 **Figure captions**

494 **Figure 1.** Location of IODP Expedition 323 sites in the Bering Sea.

495 **Figure 2.** Ostracod stratigraphic distribution at Site U1344. The sedimentary record at Site
496 U1344 spans from ~1.9 Ma to the Present. The shaded area represents the Mid-Pleistocene
497 transition (~1.2 Ma to ~0.6 Ma), which corresponds to one of the most important steps in the
498 expansion of the Northern Hemisphere ice sheets.

499 **Plate captions**

500 **Plate 1.** Scanning electron microscopy images of Bering Sea ostracods. All scale bars = 200
501 microns.

502 **1-2:** *Cytheropteron* sp. A. 1, right valve, external view, mudline sample from Hole
503 U1342A. 2, carapace, external view, sample U1344A-14H3, 144 cm.

504 **3:** *Cytheropteron* sp. B. Right valve, external view, sample U1339C-8H3, 57 cm.

505 **4:** *Cytheropteron* sp. C. Left valve external view, sample U1341A-9HCC.

506 **5:** *Cytheropteron* sp. D. Left valve external view, sample U1339D-8H4, 82 cm.

507 **6:** *Cytheropteron* sp. E. Carapace, left valve external view, mudline sample Site U1343.

508 **7:** *Microcythere medistriata* (Joy and Clark). Carapace, left valve external view, sample
509 U1343E-9HCC.

510 **8:** *Pseudocythere caudata* Sars. Carapace, left valve external view, sample U1343A-
511 9HCC.

512 **9:** *Krithe sawanensis* Hanai. 9a: left valve, internal view, sample U1344A-7H3, 148 cm;
513 9b: carapace (left valve shown), sample U1344A-8H2, 116 cm.

514 **10:** *Cluthia* sp. Left valve, sample U1344A-21H2, 110 cm.

515 **11.** *Argilloecia toyamaensis* Ishizaki and Irizuki. 11a: left valve, sample U1344A-3HCC;
516 11b: right valve, sample U1344A-11H2, 123 cm.

517 **Plate 2.** Scanning electron microscopy images of Bering Sea ostracods. All scale bars = 200
518 microns.

519 **1:** *Fallacihowellia* sp. A. Right valve, sample U1344A-2H2, 131 cm.

520 **2:** *Bradleya mesembrina* Mazzini. Right valve, sample U1341A-9HCC.

521 **3:** *Munseyella melzeri* Brouwers. 3a: Carapace, right valve shown, external view, sample
522 U1344A-23H4, 124 cm; 3b: left valve, external view, sample U1344A-23H4, 124 cm.

523 **4:** *Munseyella ristveti* Brouwers. Carapace, left valve shown, external view, mudline
524 sample from Site U1343.

525 **5:** *Robertsonites* sp. Left valve, Site U1343.

526 **6:** *Hemicytherura* sp. Left valve, external view, sample U1344A-30X2, 140 cm.

527 **7:** *Palmoconcha* sp. Left valve, external view, mudline sample from Site U1342.

528 **8:** *Eucytherura* sp. 8a: left valve, external view; 8b: right valve, external view, sample
529 U1344A-12H4, 124 cm (Late Pleistocene); 8c: carapace, right valve view, sample
530 U1344A-61X-2, 140 cm (Early Pleistocene).

531 **9:** *Cluthia* sp. Left valve, sample U1344A-21H2, 110 cm.

532 **10:** *Loxoconchidea* sp. 10a: left valve, external view; 10b: right valve, external view,
533 sample U1344A-58X2, 102 cm.

534

535 APPENDIX

536 **Systematic Paleontology**

537 Class Ostracoda Latreille 1802

538 Subclass Myodocopa Sars 1866

539 Order Halocyprida Dana 1853

540 Suborder Cladocopina Sars 1866

541 Superfamily Polycopidea Sars 1866

542 Family Polycopidae Sars 1866

543 Genus *Polycope* Sars 1866

544 *Polycope* sp.

545 Remarks: *Polycope* sp. (2 specimens) was found at Site U1344 (Sample U1344D-19H7, 2 cm
546 (172.7 m CSF-A). Distribution: Late Pleistocene.

547

548 Order Podocopa Sars 1866

549 Suborder Cypridocopina Jones, 1901

550 Superfamily Pontocypridoidea Müller 1894

551 Family Pontocyprididae Müller 1894

552 Genus *Argilloecia* Sars 1866

553 Type species. *Argilloecia cylindrica* Sars 1866

554 *Argilloecia toyamaensis* Ishizaki and Irizuki 1990

555 Pl. 1, Figs, 11a, b

556 Remarks: *Argilloecia toyamaensis* was found at Site U1344, in samples U1344A-3HCC (28.7 m
557 CSF-A) and U1344A-11H2, 123 cm (96.43 m CSF-A). *Argilloecia toyamaensis* is a cryophilic
558 species commonly found in modern and Pleistocene outer shelf to slope sediments in the
559 Okhotsk Sea and northern Japan Sea (Ozawa, 2004). Distribution: Late Pleistocene.

560

561 Suborder Cytherocopina Gründel, 1967

562 Superfamily Cytheroidea Baird, 1850

563 Family Bythocytheridae Sars, 1866

564 Genus *Pseudocythere* Sars, 1866

565 Type species. *Pseudocythere caudata* Sars, 1866

566 *Pseudocythere caudata* Sars, 1866

567 Pl. 1, Fig. 8

568 Remarks: 1 carapace of *Pseudocythere caudata* was found in core catcher sample U1343A-
569 9HCC (84.1 m CSF-A). Distribution: Late Pleistocene

570

571 Family Cytheruridae Müller, 1894

572 Genus *Cytheropteron* Sars, 1866

573 Type species. *Cythere latissima* Norman, 1865

574 *Cytheropteron* sp. A

575 Pl. 1, Figs. 1-2

576 Remarks: One recent specimen of *Cytheropteron* sp. A was found on the mudline sample from
577 Hole U1342A (818 m of water depth, Bowers Ridge, southern Bering Sea), and one fossil
578 carapace in Sample U1344A-14H3, 144 cm, at Site U1344. The specimens of *Cytheropteron* sp.
579 A are juveniles, and may belong to *Cytheropteron higashikawai* Ishizaki (Ishizaki, 1981: pl. 12,
580 figs. 6-9), but they lack the denticulate posterior edge in the alar process.

581 *Cytheropteron* sp. B

582 Pl. 1, Fig. 3

583 Remarks: One specimen of *Cytheropteron* sp. B' was found in sample U1339C-8H3, 57 cm at
584 Site U1339. The Bering Sea specimen is a small elongate species of *Cytheropteron* with a
585 delicately punctate surface ornamentation. It has a long and relatively straight with a median
586 concavity dorsal margin. A short arcuate ridge occurs mid-dorso-laterally and this branches out
587 to a second ridge that parallels the dorsal margin. The alae are short, and directed slightly
588 backward with sharp leading edge and weak zigzag ridge at the base. *Cytheropteron* sp. B
589 exhibits very strong resemblance to *Cytheropteron massoni* Whatley and Coles from the North
590 Atlantic (Whatley and Coles, 1987: pl.2, figs. 15-17). This species is also similar to

591 *Cytheropteron hanaii* Ishizaki from the East and South China Seas (Ishizaki, 1981; Zhao et al.,
592 2000).

593 *Cytheropteron* sp. C

594 Pl. 1, Fig. 4

595 Remarks: One specimen of *Cytheropteron* sp. C was found at Site U1341, in core catcher sample
596 U1341A-9HCC. This species is similar to *Cytheropteron demenocali* Yasuhara, Okahashi and
597 Cronin, from the western North Atlantic (Yasuhara et al., 2009: pl. 9, figs 1–10), and to
598 *Cytheropteron porterae* Whatley and Coles from the subpolar North Atlantic (Whatley and
599 Coles, 1987).

600 *Cytheropteron* sp. D

601 Pl. 1, Fig. 5

602 Remarks: Only one specimen of *Cytheropteron* sp. D was found at Site U1339 in the Umnak
603 Plateau, in sample U1339D-8H4, 82 cm. The specimen resembles *Cytheropteron haydenensis*
604 Brouwers, 1994 from the Gulf of Alaska by the weak, smooth ventral ridge and fine reticulation.
605 Morphologically similar forms include *C. arcticum* Neale and Howe (Quaternary, North
606 Atlantic) and *C. champlainum* Cronin (upper Pleistocene, northwest Atlantic). In the Gulf of
607 Alaska *C. haydenensis* is found in the sublittoral region (Brouwers, 1994). Distribution: Late
608 Pleistocene.

609 *Cytheropteron* sp. E

610 Pl. 1, Fig. 6

611 Remarks: One carapace of *Cytheropteron* sp. B was found in the mudline sample from Site
612 U1343 and another one in sample U1339D-8H4, 82 cm, at Site U1339 (Table 3).

613 Genus *Eucytherura* Müller, 1894

614 *Eucytherura* sp.

615 Pl. 2, Figs. 8a, b, c

616 Remarks: Found only at Site U1344. The late Pleistocene forms (Plate 2, Figs. 8a-b) are slightly
617 different in the posterior end to the early Pleistocene form (Plate 2, Fig. 8c). Seven specimens,
618 including 3 carapaces, of *Eucytherura* sp. were found at Site U1344 in samples U1344A-5HCC,
619 U1344A-12H4, 124 cm; U1344A-14H2, 120 cm; U1344A-61X2, 140 cm) (Table 3). The Bering
620 Sea species is subrhomboidal in lateral outline, tumid posteroventrally, and coarsely reticulated.
621 It lacks the eye tubercles and it has primary muri aligned sub-parallel to anterior margin.
622 *Eucytherura* sp. is somewhat similar to *Eucytherura pacifica* Ayress, Whatley, Downing and
623 Millson 1995 from the southwestern Pacific and Indian Ocean.

624 Genus *Hemicytherura* Elofson, 1941

625 Type species *Cythere cellulosa* Norman, 1865, p. 22, pl. 5, figs. 17, 20, pl. 6, fig. 17

626 *Hemicytherura* sp.

627 Pl. 2, Fig. 4

628 Remarks: a single valve was found in Sample U1344A-30X2, 140 cm. Distribution: mid
629 Pleistocene.

630

631 Family Eucytheridae Puri, 1954

632 Genus *Eucythere* Brady, 1868

633 *Eucythere* sp.

634 Remarks: a single specimen of *Eucythere* sp. was found in Sample U1344A-9H5, 144 cm.

635

636 Family Leptocytheridae Hanai 1957a

637 Genus *Cluthia* Neale, 1973

638 Type species. *Cythere cluthae* Brady, Crosskey and Robertson 1874

639 *Cluthia* sp.

640 Pl. 1, Fig. 10

641 Remarks: *Cluthia* sp. was found at Site U1344 in samples 3HCC (at 28.7 m CSF) and U1344A-
642 21H2, 110 cm (at 191.48 m CSF). This taxon was referred to as *Nannocythere delicata* (Whatley
643 and Eynon 1995) and *Nannocythere* sp. by Whatley et al. (1998), Didié and Bauch (2000) and
644 Alvarez Zarikian (2009), however, there are some problems with the nomenclature. For this
645 reason here I follow the taxonomy of Yasuhara and Okahashi (in press) for its generic
646 classification. Distribution: Late Pleistocene.

647

648 Family Loxoconchidae Sars, 1926

649 Genus *Palmoconcha* Swain and Gilby 1974

Type species. *Palmoconcha laevimarginata* Swain and Gilby 1974

Palmoconcha sp.

Pl. 2, Fig. 7

Remarks: a single specimen of this species was found on a mudline sample from Site U1342 (818 m of water depth) on the Bowers Ridge, southern Bering Sea. The specimen, illustrated in plate 2, figure 8, matches the diagnostic description for the genus *Palmoconcha*, a loxoconchoid genus with valves having markedly flattened flange-like terminal marginal areas and coarsely pitted or reticulate general surface (Swain and Gilby, 1974). Species of this genus are known from the sublittoral to upper bathyal zones.

Genus *Loxoconchidea* Bonaduce, Ciampo and Masoli, 1976

Type species. *Loxoconchidea minima* Bonaduce, Ciampo and Masoli, 1976

Loxoconchidea sp.

Pl. 2, Figs. 10a, 10b

Remarks: a fragmented carapace was found in Sample U1344A-58X2, 102 cm (543 m CSF). *Loxoconchidea* sp. is very similar to *Loxoconchidea dolgoiensis* Brouwers from the Gulf of Alaska (Brouwers, 1993), but because of the fragmented valves it wasn't possible to confidently assign the Bering Sea specimen to *L. dolgoiensis*. Distribution: Lower Pleistocene: central Japan; Pleistocene through Holocene in northeast Gulf Alaska where it is found from middle to outer shelf, to the upper slope.

670

671 Family Krithidae Mandelstam, 1958 (in Bubikyan, 1958)

672 Genus *Krithe* Brady, Crosskey and Robertson, 1874

673 Type species. *Ilyobates praetexta* Sars, 1866

674 *Krithe sawanensis* Hanai 1959

675 Pl. 1, Fig. 9a, b

676 Remarks: *Krithe* is the most abundant and widespread ostracod genus in the deep sea. Likewise,
677 it is the most common genus in the Bering Sea samples. Only *Krithe sawanensis* was identified
678 in the present study. *K. sawanensis* is common in lower shelf to continental slope areas of the
679 northwestern Pacific (Ozawa 2003). *K. sawanensis* is morphologically similar to *Krithe*
680 *burkholderi* Brouwers from the Gulf of Alaska (Brouwers, 1990) or *Krithe glacialis* (Brady,
681 Crosskey and Robertson) from the Arctic and North Atlantic Ocean (Whatley et al. 1998;
682 Stepanova et al. 2003).

683

684 Family Microcytheridae Klie, 1938

685 Genus *Microcythere* Müller, 1894

686 Type species *Microcythere medistriata* (Joy and Clark, 1977), Pl. P8, figs. 7, 8 (Joy and Clark,
687 1977).

688 *Microcythere medistriata* (Joy and Clark, 1977)

Pl. 1, Fig. 7

Remarks: *M. medistriata* was found at Site U1344, sample U1344A-38X2, 140 cm (one carapace), and at Site U1343, core catcher sample U1343-9HCC (one valve). This is the first report of this species outside of the Arctic Ocean (Joy and Clark, 1977; Briggs, 1997; Poirier et al., 2012; and Cronin et al., 2013) and the subpolar North Atlantic (Alvarez Zarikian, 2009). This species occurs in significant numbers in the western Arctic Ocean, where it is characteristic of intermediate water masses (Poirier et al., 2012). *M. medistriata* is also considered to possibly be linked to increased sea ice cover (Cronin et al., 2013).

Family Pectocytherini Hanai, 1957

Genus *Munseyella* van den Bold, 1957

Type species. *Toulminia hyalokystis* Munsey, 1953

Munseyella melzeri Brouwers 1990

Pl. 2, Fig. 3a, 3b

Remarks: Found at Sites U1343 and U1344. Material: two carapaces and three single valves. This species was described by Brouwers (1990) from the Gulf of Alaska. *M. melzeri* is characterized by weak ornament ridges, V-shape ridge in anteromedian region, robust posterior marginal denticles and convergent posterior. It also closely resembles *Munseyella* sp. 3 from the Okhotsk Sea (Ozawa and Tsukawaki, 2008: pl. 2, fig. 10). In the Gulf of Alaska, this species is found in Pleistocene through Holocene sediments in the middle to outer sublittoral zone

(Brouwers, 1990). In the Okhotsk Sea, it is found on shelf sediments at ~100 m water depth
(Ozawa and Tsukawaki, 2008). Distribution: Mid to Late Pleistocene at Site U1344.

Munseyella ristveti Brouwers 1990

Pl. 2, Fig. 4

Remarks: only one carapace was found at Site U1343. *M. ristveti* was described from Holocene
deposits from the middle to outer shelf of the Gulf of Alaska (Brouwers, 1990).

Family Trachyleberididae Sylvester-Bradley, 1948

Genus *Bradleya* Hornibrook, 1952

Type species. *Cythere cluthae* Brady, Crosskey and Robertson 1874

Bradleya mesembrina Mazzini 2005

Pl. 2, Fig. 2

Remarks: two specimens were found in Sample U1344A-20H4, 130 cm, and one in Sample
U1341A-9HCC. *B. mesembrina* was originally described from Holocene sediments in the South
Tasman Rise at depths of 1636-3022 m (Mazzini, 2005), and its previously known distribution
extends to Late Pleistocene and Recent sediments in Antarctic and sub-Antarctic zones of the
Southern Ocean at a depth range of 231–4420 m (Brandão and Päpłow, 2011). This is the first
record of *B. mesembrina* in the North Pacific. Distribution: Late Pleistocene in the Bering Sea.

728 Genus *Apatihowella* (*Fallacihowella*) Jellinek and Swanson 2003

729 Type species. *Apatihowella* (*Fallacihowella*) *sol* Jellinek and Swanson 2003

730 *Fallacihowella* sp. A sensu Mazzini 2005

731 Pl. 2, Fig. 1

732 Remarks: *Fallacihowella* sp. A sensu Mazzini 2005 is the second most abundant ostracod
733 species in the Bering Sea samples (12 specimens). It was found at Sites U1339 (Umnak Plateau),
734 U1341 (Bowers Ridge) and U1344. The specimens found in the Bering Sea are similar to
735 *Fallacihowella sol* Jellinek and Swanson (Jellinek and Swanson, 2003; pl. 34 figs. 1-10; pl. 35
736 figs. 1-6), but it is identical to Mazzini (2005)'s *Fallacihowella* sp. A from the Tasman Sea and
737 the Southern Ocean. Mazzini (2005) indicates that *Fallacihowella* sp. A differs from *F. sol*
738 because of its larger dimensions. Moreover, *Fallacihowella* sp. A is considered to be adapted to
739 narrow ecological gradients, living in diatom/radiolarian ooze with a very low carbon content
740 (Mazzini, 2005), the sedimentological setting as in the Bering Sea. This is the first record of *B.*
741 *mesembrina* in the North Pacific. Distribution: mid Pleistocene to Holocene.

742

743 Genus *Robertsonites* Swain, 1963

744 Type species. *Robertsonites gubikensis* Swain, 1963

745 *Robertsonites* sp.

746 Pl. 2, fig. 5

747 Remarks: a juvenile valve of *Robertsonites* sp. was found at Site U1343. The species of
748 *Robertsonites* at Site U1343 is similar to *R. hanaii* Tabuki (see Tabuki, 1986: pl. 13, figs.
749 1-12), but the latter has a coarser reticulate surface than the Bering Sea form.
750 *Robertsonites* sp. differs from *R. tuberculata* (Sars) by the lack of posterodorsal and
751 posteroventral nodes characteristic of the latter species (Hazel, 1967: pl. 6, figs. 1-3). The
752 genus *Robertsonites* is widely distributed in high latitude seas of the Northern
753 Hemisphere and it is common in fossil ostracod faunas in Plio-Pleistocene deposits in
754 Japan (Ikeya and Cronin, 1993). The genus is common in ostracod assemblages in muddy
755 sediments of the lower continental shelf and slope areas of the present day Japan Sea,
756 where the water temperature remains at 0–5 degrees Celsius throughout the year (e.g.
757 Ozawa, 2003; Ozawa and Kamiya, 2005).

Figure 1.

Figure 2.