1 Holocene evolution of diatom and silicoflagellate paleoceanography in Slocum
2 Arm, a fjord in southeastern Alaska

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11 ABSTRACT

12 Diatom and silicoflagellate assemblages in cores EW0408-47JC, -47TC, -
13 46MC (57° 34.5278' N, 136° 3.7764' W, 114 m water depth) taken from the outer
14 portion of Slocum Arm, a post-glacial fjord in southeastern Alaska, reveal the
15 paleoclimatic and paleoceanographic evolution of the eastern margin of the Gulf
16 of Alaska (GoA) during the past 10,000 years. Between ~10 and 6.8 cal ka,
17 periods of low salinity and cool water conditions alternated with brief intervals
18 marked by the increased influx of oceanic, more saline and likely warmer waters.
19 Increased surface water stability characterized by a middle Holocene interval
20 between ~6.8 and 3.2 cal ka is typified by increased abundances of northeastern
21 Pacific *Thalassiosira* spp. that are indicative of spring coastal blooms and
22 decreased abundances of warm and higher salinity oceanic diatoms. At ~3.2 cal
23 ka, an abrupt increase in both the relative contribution of oceanic diatoms and
24 silicoflagellates suggestive of cooler upwelling conditions occurred in the -47JC
25 record. A stepwise increase in alkenone sea surface temperature in northern
26 GoA core EW0408-85JC and an increase in southern sourced precipitation
27 indicated by the Jellybean Lake (Yukon) carbonate-d18O record, present
28 evidence that this ~3.2 cal ka event coincided with the onset of enhanced
29 positive Pacific Decadal Oscillation-like (PDO) conditions in the GoA. These
30 positive PDO-like conditions persisted until ~1.0 cal ka and were followed by high
31 amplitude fluctuations in the relative abundance of diatom and silicoflagellate
32 assemblages.

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1. Introduction

1.1 Setting

The Gulf of Alaska (GoA), located in the subarctic eastern North Pacific Ocean, covers an area that exceeds 1.5 million km². The GoA includes a variety of different marine environments, such as a vast abyssal plain, numerous seamounts, and extensive continental shelves. Along the southeast margin of the GoA lies the Alexander Archipelago (also called Southeast Alaska), which is composed of more than a thousand small islands. The coastal boundaries of many of these islands are dotted with steep-sided fjords, the majority of which are classified as temperate fjords (Syvitski et al., 1987), as they remain largely ice-free year round.

The fjords of the Alexander Archipelago are an important habitat for many marine species of local and regional interest, such as Pacific salmon (e.g., Murphy et al., 2011), cetaceans (Dahlheim et al., 2009), and pinnipeds (Womble et al., 2014). However, the past variability of the marine ecosystem of the Alexander Archipelago is poorly studied. In this analysis, we present new diatom and silicoflagellate data from marine sediment core EW0408-47JC in Slocum Arm fjord on Chichagof Island. These data are (1) compared against similar micropaleontology results from other previously published GoA sites to examine common temporal trends in siliceous microfossil variability during the Holocene, and (2) placed in a regional paleoclimate context using other key records to test

the hypothesis that the Slocum Arm microfossil assemblage variability reflects a common response to regional atmospheric and/or ocean forcing mechanisms.

1.2 Oceanography

Ocean circulation in the Gulf of Alaska (Fig. 1a) is dominated by the Alaska Gyre in the central basin, the Alaska Current on the continental shelf, and the Alaska Coastal Current (ACC) along the margin. The Alaska Gyre is a micronutrient-limited zone of domal upwelling with a cyclonic rotation that drives lateral advection of high-nutrient-low-chlorophyll (HNLC) surface waters towards the continental shelf margins of the GoA (Bograd et al., 1999; Harrison et al., 1999). As these HNLC waters approach the coastal zone, they coalesce and flow northwards as the Alaska Current, which is the northward extension of the North Pacific Current that defines the Subarctic Front in the Northeast Pacific Ocean (Yuan and Talley, 1996). The ACC is responsible for transporting ~40% of the net freshwater flux from GoA terrestrial run-off and fluvial discharge north of 50°N latitude (Royer, 1982; Weingartner et al., 2005). Both buoyancy (low salinity) and wind shear traps the ACC to a narrow surface band along the coastal GoA margin (Stabeno et al., 2004). While upwelling occurs in the central GoA, the interaction between the advected waters from the central Alaska Gyre and the ACC contribute to observed coastal downwelling (Weingartner et al., 2002).

The interplay between atmospheric dynamics and ocean circulation over the annual cycle is the first-order control on marine ecosystem productivity in the

GoA. During the winter, storms associated with intensified Aleutian Low conditions (Rodionov et al., 2007) force strong vertical mixing which entrains subsurface nutrients into shallower depths (Childers et al., 2005). During the subsequent late spring, summer, and early fall, regional phytoplankton blooms are observed in SeaWiFS satellite imagery from the Southeast Alaska margin (Addison et al., 2013; Waite and Mueter, 2013). These blooms are thought to be driven by a combination of high surface nutrient concentrations advected from the Alaska Gyre, increased summer solar insolation, shallower mixed layer depths, and stronger salinity stratification from ACC-derived waters (Gargett, 1997; Strom et al., 2010; Di Lorenzo et al., 2013). Enhanced micronutrient availability in the coastal environment may further enhance phytoplankton productivity (Nishioka et al., 2001; Severmann et al., 2010; Johnson et al., 2005; and Crusius et al., 2011).

Strong evidence for interannual and decadal variability abounds in the Gulf of Alaska. Several system-wide indices have been developed to describe this variability, such as the North Pacific Index (NPI; Trenberth and Hurrell, 1994) that is based on sea level pressure, the Pacific (Inter)Decadal Oscillation (PDO; Mantua et al., 1997) which uses sea surface temperatures, and the North Pacific Gyre Oscillation (NPGO; Di Lorenzo et al., 2008) which is calculated using sea surface height. It should be noted that these indices all correspond to some combination of GoA-based parameter (e.g., atmosphere, ocean, and/or biological), of which at least 40 have been identified as having some sort of canonical change during the AD 1976/1977 North Pacific “Regime Shift”

(Ebbesmeyer et al., 1991). A positive feedback mechanism is thought to exist in the GoA, such that periods of intensified Aleutian Low atmospheric dynamics (e.g., + PDO regimes) favor (i) greater upwelling and advection of nutrient-rich waters from the Alaska Gyre to the GoA margin; (ii) enhanced vertical mixing from storms; and (iii) increased freshwater discharge into the ACC, all of which can contribute to greater coastal marine ecosystem productivity (e.g., Gargett, 1997).

1.3 Previous Studies of Paleoceanography

Recent studies reveal that the paleoclimatology and paleoceanography of the subarctic northeastern Pacific, Gulf of Alaska and eastern Bering Sea, have experienced a complex evolution during the Holocene,

Barron et al.'s (2009) study of piston core EW0408-85JC (Fig. 1) from the northern GoA revealed a Holocene record dominated by oceanic North Pacific diatoms and silicoflagellates, with northeastern Pacific coastal *Thalassiosira* (*T. pacifica* and small, related taxa) increasing between ~6 and 3 cal ka, suggesting a weakened Aleutian low pressure system (AL). On the other hand, diatoms and silicoflagellates indicative of high nutrient conditions dominated the entire post 11-cal ka record of piston core EW0408-11JC from the southeastern Alaskan margin (Fig. 1). Sea ice-related diatoms there were largely restricted to the interval older than ~11 cal ka.

Davies et al. (2011) and Addison et al. (2012) presented high-resolution deglacial and Holocene records of geochemistry, biogenic silica, and benthic and planktic foraminiferal isotopes for core EW0408-85JC. Although the majority of their discussion dealt with deglacial changes occurring between ~17 and 11 cal ka, some observations of the Holocene record were made. Planktic foraminiferal $\delta^{18}\text{O}$ suggested that the surface ocean gradually cooled and/or increased in salinity until ~7.7 cal ka, after which a warming and/or freshening trend occurred. Davies et al. (2011) noted that the difference between planktic and benthic foraminiferal $\delta^{18}\text{O}$ increased for ~600 years beginning at ~2.5 cal ka, an increase that they attributed to glacier advance in coastal Alaska. Biogenic silica values peaked at ~10% at ~11 cal ka and then rapidly declined to a baseline level of ~6% until ~4 cal ka, after which values fluctuated between ~4 and 6% (Davies et al., 2011; Addison et al., 2012).

Praetorius et al. (2015) studied the high-resolution paleoceanography of the last 20,000 years at EW0408-85JC, concentrating on the deglacial to earliest Holocene (20 to 10 cal ka). They presented a new alkenone SST record for -85JC and compared it to the alkenone sea surface temperature (SST) record of ODP Site 1019 off northernmost California. The post-10 cal ka alkenone SST records of these two cores are remarkably similar, displaying gradual declines in SST of >1.0°C between ~8.5 and 7.0 cal ka, generally cooler conditions between ~7.0 and 4.0 cal ka, and an ~1.0°C increase in SST between 4.0 and 3.0 cal ka. The ~3.0 to 1.5 cal ka period of maximum late Holocene SSTs in -85JC coincides with increased variability in the biogenic silica record and with enriched values of

$\delta^{18}\text{O}$ of seawater, which is suggestive of increased salinity and possibly enhanced productivity.

Caissie et al. (2010) reported on late Glacial and Holocene sea surface conditions in the southeastern Bering Sea based on diatom, alkenone, and stable isotope records. They noted that at 11.3 cal ka the diatom assemblage shifted from one dominated by sea ice-related species to one dominated by warmer water, North Pacific species. Alkenone SSTs increased by 3°C during this earliest Holocene interval, but they exhibited little change thereafter other than a gradual ~+1°C trend between ~5 and 3 cal ka.

The evolution of atmospheric circulation in the GoA area was addressed by Anderson et al. (2016), who presented an overview of 18 Holocene lake isotope (carbonate $\delta^{18}\text{O}$) Rocky Mountain records ranging from southeast Alaska to southern Colorado. They separated the two Holocene length lake records that reflected the isotopes of precipitation from those that reflected evaporation and reconstruct Holocene atmospheric circulation patterns by their comparison (Bison Lake, Colorado and Jellybean Lake, Yukon). Based on a prominent north-south precipitation-isotope dipole indicated by the two records, they hypothesized that the subtropical influence on the GoA, as we know it today, developed between ~3.5 and 1.5 cal ka.

2. Materials and methods

Slocum Arm is a postglacial fjord, extending ~23 km northwestward along the western margin of Chichagof Island (Fig. 1b). It is typically 1-2 km wide, with a narrow postglacial central channel that is 120 to 220 m deep. Although its southern half is separated from the GoA by a broad peninsula, its northern one third, where core- 47JC is located possesses shallow channels between western islands that allow for greater input of GoA surface waters. High-resolution bathymetry data from Slocum Arm (Fig. 1c) show the shallowest sill is ~85 m deep.

Three cores were taken in Slocum Arm, EW0408-47JC, a jumbo piston core, EW0408-47TC, a trigger weight core, and EW0408-46MC, a multi core. Collectively, they will be referred in this report to as the -47JC cores. They were all collected at 57° 34.5278' N, 136° 3.7764' W, at a water depth of 114 m (Fig. 1c).

A composite depth scale was constructed that aligned both the EW0408-47JC jumbo piston core and the EW0408-47TC trigger core with EW0408-46MC using similar stratigraphic features identified in GEOTEK Multi-Sensor-Track core logger data (e.g., gamma-ray-attenuated GRA wet bulk density and whole-round magnetic susceptibility) that was collected after core recovery (Fig. 2). This composite depth scale places the top of the -47JC jumbo piston core at the 42 cm level of -46MC and the top of the -47TC trigger core at the 24 cm level of -46MC.

2.1 Diatoms

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194 Strew slides for diatoms and silicoflagellates were prepared by placing
195 about ~0.2 cc of sediment in a glass vial and covering it with 7-10 times as much
196 distilled water as sample. A disposable wooden stick was then used to
197 disaggregate the samples in the vials by stirring the suspension. To prepare
198 slides, the vial was shaken and a drop of the suspension was taken after 5-10
199 seconds of settling from near the top of the vial, transferred to a 40 x 22 mm
200 cover slip and dried at low heat on a hot plate. Slides were then mounted in
201 Naphrax (index of refraction = 1.74).

202 Diatom relative abundances were estimated by recording the number of
203 diatom valves encountered while making vertical traverses of the slide (length of
204 traverse = 22 mm) at 790X using the counting techniques of Schrader and
205 Gersonde (1978). Vertical traverses were made until >300 diatom valves were
206 counted. The ratio of *Chaetoceros* resting spores to diatoms was estimated
207 independently by a count of 100+ specimens at 1,250X.

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209 2.2 *Silicoflagellates*

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211 Silicoflagellates are diluted by diatoms and by coarse silt. One or two
212 slides were systematically tracked to obtain a representative count of at least 100
213 specimens per sample. Counts typically were made at 250X magnification, with
214 500X used for checking questionable specimens. All whole specimens and half
215 specimens with intact apical structures were counted. Five test tracks (40 mm in

length) were made on diatom slides prepared for each sample. Samples containing fewer than 10 silicoflagellates were not counted. Silicoflagellates were tabulated on one to three slides until 100 specimens were counted. Five samples containing fewer than 100 silicoflagellates but greater than 50 specimens were included (Supplementary Table 2). Taxonomy follows that used by Bukry (1973, 1980, 1981), as updated by Jordan and McCartney (2015). Intraspecific variants of silicoflagellate taxa were tabulated in an effort to determine paleoecologic preferences.

2.3 Chronology

The chronology for EW0408-47JC is based on 13 accelerator-mass-spectrometry (AMS) ^{14}C dates on a combination of well preserved marine bivalve shells and terrestrial plant macrofossils, as well as a middle Holocene (~6.407 to 6.725 cal ka) rhyolitic tephra from the Mount Edgecumbe volcanic field (Addison et al., 2010), and the recovery of an intact sediment-water interface in the corresponding multicore sample EW0408-46MC that dates to AD 2004 (Table 1). Calibration of all marine samples was performed using the Marine13 curve and all terrestrial plant samples using IntCal13 (Reimer et al., 2013). For the marine samples, a reservoir value of 735 +/- 50 years was applied [$\Delta R = 335 \pm 50$ yrs] (Praetorius and Mix, 2014).

Age-depth models for the composite EW0408-47JC core suite (Fig. 2a) were calculated using the R-based program CLAM (v.2.2; Blaauw, 2010). The

CLAM program used the 2-sigma calibration range of each date with weighting by calibrated probabilities, 10,000 Monte Carlo-style iterations, and calendar age-point estimates for depths that were based on the weighted average of all non-reversing age-depth curves.

2.4 Factor Analysis

Factor analysis using the principal component analysis (PCA) method was conducted on a subset of the diatom population assemblage to identify general patterns that were common amongst the input diatom assemblage. Species and/or functional groups were selected that contained at least 30 non-zero observations, and all percentage concentration data underwent log-normal transformations (Aitchison, 1986, 1999) prior to analysis using the IBM SPSS (v.22) software package. The PCA was calculated using the correlation matrix approach and a Varimax rotation with Kaiser normalization. For the cases where no observations exist in individual datasets, population mean values were substituted.

2.5 Diatom Proxies

Formal citations of the diatom taxa tabulated in the three cores are listed in the appendix along with notes about possible synonyms. The diatoms can be divided into differing ecological groups as discussed below.

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263 2.5.1 *Chaetoceros* spores

264 *Chaetoceros* resting spores are indicative of coastal upwelling in
265 traditional eastern boundary current settings (Lopes et al., 2006), but they are
266 also common in other nutrient-rich waters. As they are resistant to dissolution, it
267 is commonly difficult in bulk sediment studies to determine whether they were
268 deposited as part of a bloom or represent redeposition by bottom currents.
269 Consequently, they were counted independently from the diatom censuses.

270

271 2.5.2 *Transported Diatoms*

272 Transported diatoms include benthic, freshwater and reworked fossil
273 diatoms. The presence of these diatoms in the assemblages at the core site is
274 due to transport from shallower areas of the fjord.

275

276 2.5.3 *Temperate Oceanic Diatoms*

277 *Thalassionema nitzschioides* is a cosmopolitan diatom that is common in
278 offshore productive regions of the North Pacific (Sancetta and Silvestri, 1986).
279 Ren et al. (2014) note that although *T. nitzschioides* is most common in
280 temperate to subtropical settings along the western margin of North America
281 south of the Subarctic Front, it is also common along the southeastern and
282 northern margins of the GoA, where it appears to be a proxy for productivity
283 along the coastal edges of the Alaska Current.

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2.5.4 Subtropical Oceanic Diatoms

Following Ren et al. (2014), *Thalassiosira eccentrica*, *T. lineata*, *T. oestrupii*, *Azpeitia tabularis*, *Fragilariopsis doliolus*, and *Nitzschia* sp. cf. *N. bicapitata* are considered as subtropical oceanic taxa, meaning that they are open ocean diatoms that are common in subtropical to temperate waters of the North Pacific (see also Sancetta and Silvestri, 1986; Sancetta, 1992; Lopes et al., 2006).

2.5.5 Northeastern Pacific Coastal Bloom *Thalassiosira*

Thalassiosira pacifica and small (<10µm in diameter) *Thalassiosira* (*T. decipiens* and *T. spp.*) are considered coastal northeastern Pacific bloom indicators after Sancetta (1982), McQuoid and Hobson (2001), Katsuki and Takahashi (2005), Lopes et al. (2006), and Hay et al. (2007). We separate smaller forms having more regular areolar patterns from *T. pacifica* (Barron et al., 2009) as *T. angulata* (see Taxonomic appendix). These *Thalassiosira* species are adapted to low light and cool surface waters that are typical of the spring bloom in coastal British Columbia (Galloway et al., 2013).

2.5.6 Arctic Diatoms

The Arctic factor of Ren et al. (2014) is dominated by *Bacteriosira bathyomphala* (= *B. fragilis*), *Fragilariopsis oceanica* (= *Nitzschia grunowii*), and *F. cylindrus*. Also important are *Thalassiosira antarctica* var. *borealis* resting spores

(often identified in other studies as *T. gravida*), *T. hyalina*, and *T. nordenskioeldii*, with minor contributions from *Porosira glacialis*.

Among these, diatoms associated with sea ice, either in ice marginal waters or with the bloom that immediately follows the break-up of sea ice, include *B. bathyomphala*, *P. glacialis*, *T. antarctica* var. *borealis* and its resting spores, *T. hyalina*, and *T. nordenskioeldii*. Hasle and Heimdal (1968) report that *T. antarctica* var. *borealis* is restricted to coastal or ice-margin waters, in conditions of low temperature (-1 to 4°C) and salinity (25-34 ‰). *Fragilariopsis cylindrus* and *F. oceanicus* are considered as definite proxies for sea ice by Horner and Alexander (1972) and Sancetta (1981); however, von Quillfeldt (2004) argues that *F. cylindrus* may indicate cold water rather than sea ice. Areas under the influence of newly melted ice in the southeastern Bering Sea had dense populations of *T. hyalina*, *T. nordenskioeldii* and *Fragilariopsis* spp. according to Schandelmeier and Alexander (1981).

2.5.7 Subarctic Oceanic Diatoms

Neodenticula seminae is associated with cold subarctic waters of the North Pacific (Sancetta and Silvestri, 1986; Takahashi, 1997). According to the sediment trap studies of Takahashi (1997), *N. seminae* is the dominant productivity factor in the south central GoA (Station PAPA, Fig. 1a), which is typified by moderate SSTs (6-7°C) and relatively high salinity (>33 ‰) (Sancetta, 1982). Ren et al. (2014) state that *N. seminae* is most dominant in

their subarctic factor, being found in North Pacific waters north of the Subarctic Front and corresponding with sea surface temperatures between 8° and 15°C.

Sancetta and Silvestri (1986) consider *Thalassiosira trifulta* and *Actinocyclus curvatulus* to be indicative of cold, low-salinity surface water found in the Sea of Okhotsk in the spring after melting of the winter sea ice. Ren et al. (2014) show that these two species are also common in colder waters of the northwestern Pacific north of the Subarctic Front, considering them to be important contributors to their Subarctic factor.

2.6 Silicoflagellate Proxies

The formal citations of the silicoflagellate taxa tabulated in the three cores are listed in the appendix along with notes about possible synonyms. The silicoflagellate genus name *Distephanus* has recently been replaced by the new genus name *Stephanocha* (Jordan and McCartney, 2015). We follow this taxonomy but include the genus *Distephanus* in parenthesis for clarity. The silicoflagellates can be divided into ecological groups as discussed below.

2.6.1 Upwelling silicoflagellates

The various forms of *Stephanocha* (previously *Distephanus*) *speculum* indicate the presence of cooler, nutrient-rich waters that occur in regions of coastal upwelling (Poelchau, 1976; Takahashi et al., 1989; Barron et al., 2009). As summarized in Barron et al. (2009), *Stephanocha speculum* var. *minuta*

increases its relative numbers poleward compared to populations of other *S. speculum* varieties, suggesting that it is a proxy for cooler water upwelling.

2.6.2 Subarctic silicoflagellates

Stephanocha (previously *Distephanus*) *octangulata* is a subarctic silicoflagellate that is most common in cooler waters of the Bering Sea and Alaskan Gyre (Ling, 1973; Poelchau, 1976; Takahashi, 1997).

2.6.3 Subtropical silicoflagellates

Dictyocha stapedia f. *spinosa* (*D. messanensis* of Takahashi, 1997) ranges from the equatorial to the subarctic North Pacific (Poelchau, 1976).

2.6.4 Deep thermocline silicoflagellates

Dictyocha aculeata s.l. ranges from the tropical Pacific to the GoA (Poelchau, 1976; Barron et al., 2009). It appears to represent the presence of a deeper thermocline, in contrast to the *Stephanocha speculum* group, which thrives in shallow thermocline conditions associated with coastal upwelling (Barron and Bukry, 2007).

3. Results

3.1 Lithology

The EW0408-47JC core suite is a continuous sediment record that extends from the modern sediment-water interface to a maximum penetration depth of 1863 cm below the sea floor (cm bsf). It is predominantly composed of dark olive gray (Munsell color code 5Y3/2) clay with frequent occurrences of articulated bivalve shells and crushed shell fragments, and occasional discrete shell hash horizons and terrestrial wood fragments. The split core faces appear homogenous under standard light conditions suggesting intensive bioturbation, but preliminary computerized tomography (CT) scanning (e.g., Addison et al., 2013) shows that the bioturbation is not continuous throughout 47JC, nor of constant intensity, as distinct laminations are present in the CT scans interspersed between zones with visible biogenic features (e.g., burrows, escape traces, etc.; Addison, unpublished data). Preliminary smear slide analyses of 47JC reveal the common occurrence of diatoms and sponge spicules, the presence of calcareous nannofossils, and rare occurrences of foraminifera, radiolarians, plant fragments, and mollusk shell fragments.

3.2 Chronology

The calibrated composite chronology for EW0408-47JC shows that it extends continuously from AD 2004 to a basal age of ~10,000 cal yr BP, just short of the Last Glacial Maximum - Holocene transition (Table 1). The largest 2-sigma calibration range was observed for a plant macrofossil (9,746 to 10,176 cal yrs BP) at 1822 composite cm below sea floor, which serves as the lowest

directly dated horizon in the EW0408-47JC composite chronology. A set of paired bivalve-wood AMS ^{14}C dates at 1170 composite cm bsf show an offset of 735 ^{14}C yrs, which supports the use of the reservoir value of Praetorius and Mix (2014) for the EW0408-47JC composite chronology.

Several CLAM age-depth models were evaluated against one another, and a smooth loess-type model was selected to plot the micropaleontology samples (Fig. 2a). This model shows a smooth fitting of all the age control points, and has a median 2-sigma error range of ~170 years per cm. A key feature is a background change in sedimentation rate that occurs between ~750 and 700 cm or ~7.6 cal ka; above this interval, the median sedimentation rate for EW0408-47JC is ~0.1 cm/yr, and below it is ~0.45 cm/yr (Fig. 2b). Comparison of downcore GRA bulk density (Fig. 2c) reveals no distinct change across this ~7.6 cal ka change in sedimentation rate that is suggestive of a critical change in the sedimentary environment of Slocum Arm.

3.3 *Diatoms*

The down-core record of relative abundances of different ecological groups of diatoms in cores -47JC, -47TC, and 46MC is displayed in Figure 3. Diatom census data are available in supplementary Table 1.

Chaetoceros spores typically constitute between 60 and 80% of the total diatom assemblage, attesting to the strong influence of diatom blooms driven by the advection of nutrient-rich intermediate zone waters into Slocum Arm by

reverse estuarine circulation (see Addison et al., 2013, Fig. 2a). The amplitude of *Chaetoceros* spore relative abundance appears to be greatest (20-30%) in the middle part of the record between ~6 and 2 cal ka.

Transported diatoms (benthic, reworked, and freshwater diatoms) together make up between 20 and 40% of the *Chaetoceros*-free diatom assemblage in broad cycles typically lasting ~1500 to 200 years (supplementary Table 1).

Figure 3 displays the major diatom taxa by their climatic/oceanic preferences. The major portion of the *Chaetoceros*-free diatom assemblage is made up of *Thalassiosira angulata* (likely *T. pacifica* of other studies), *Thalassionema nitzschioides*, and *Thalassiosira nordenskiöldii*. These three taxa comprise an average of 38% of the assemblage.

Thalassiosira angulata is the most important contributor to the northeastern Pacific coastal bloom *Thalassiosira* group, with intervals of increased (>20%) relative abundance occurring between ~6.8 and 3.2 cal ka and between ~0.9 and 0.2 cal ka. Conversely, *Thalassionema nitzschioides*, a cosmopolitan diatom that is common in offshore productive regions of the North Pacific, tends to be most common (>15%) during intervals marked by reduced *T. angulata*, particularly between ~3.2 and 1.0 cal ka as well as during brief intervals centered on ~9.4, 8.1, and 7.5 to 7.0 cal ka. *Thalassiosira oestrupii*, a subtropical to temperate diatom (Ren et al., 2014), increases in relative abundance during many of the same intervals as *T. nitzschioides*. These intervals possibly indicate more warmer waters associated with increased salinity,

Thalassiosira nordenskioeldii is by far the most common of the Arctic diatoms, rising in relative abundance to >6% during much of the -47JC record between ~8.5 and 3.2 cal ka. In sample -47JC, 800-801 cm (~7.6 cal ka) *T. nordenskioeldii* increases to ~35% of the diatom assemblage. Other Arctic and sea-ice related diatoms make up >3% of the diatom assemblage.

Subarctic diatoms (*N. seminae*, *A. curvatulus*, and *T. trifulta*), which prefer summer SSTs >8°C (Ren et al., 2014), comprise <5% of the diatom assemblage.

3.4 Silicoflagellates

Figure 4 displays the -47JC the downcore record of relative abundances of different ecological groups of silicoflagellates. Silicoflagellate census data are available in supplementary Table 2.

The *Stephanocha speculum* group predominates the -47JC record with minor contributions of *Dictyocha* sp. cf. *D. aculeata* (never exceeding 9%, usually <5%). Below ~3.4 cal ka *S. speculum* s.s. and the cooler-water form *S. speculum* var. *minuta* display alternating dominance cycles that occur roughly every ~500 to 1000 years. After ~3.4 cal ka, *S. speculum* var. *minuta* is consistently more common, especially prior to ~1.4 cal ka.

Other *S. speculum* forms, *S. speculum* var. *ornamentata* and the coronatid form of *S. speculum* are most common prior to ~7.6 cal ka, with a distinctive peak of ~16% in the former occurring in the sample from 800-801 cm (~7.6 cal ka), which is the sample containing a peak abundance of the diatom *T.*

nordenskioeldii. *Stephanocha* (*Distephanus*) *speculum* var. *ornamentata* is a seven-spined taxon and a prominent member of recent Arctic Ocean sea-ice floras (Takahashi et al, 2009), which could suggest a cold, lower salinity event.

Dictyocha sp. cf. *D. aculeata* displays sporadic abundance cycles of ~5 to 9% of the silicoflagellate assemblage at ~9.9 to 9.7, 8.4, 5.0 to 4.6, 3.0, and between ~1.15 and 0.76 cal ka.

Subarctic *Stephanocha octangulata* and subtropical *Dictyocha stapedia* f. *spinosa* are both rare with sporadic relative abundance peaks that never exceed 3% of the silicoflagellate assemblage.

4. Discussion

4.1 Comparison with other Diatom Records from the Southeastern Alaskan Margin

Marine sediment core EW0408-11JC (Fig. 1b) lies about 300 km southeast from EW0408-47JC in a semi-enclosed embayment setting in the Gulf of Esquibel (Fig. 1b), and it could be expected that its diatom and silicoflagellate record (Barron et al., 2009) would be similar to that of -47JC record. Figure 5a compares the relative percentage contributions of *T. nitzschioides*, coastal bloom *Thalassiosira* (*T. angulata*, *T. pacifica*, and *T. decipiens* of this report), and *T. nordenskioeldii* between the two cores. *Thalassiosira angulata* was not distinguished from *T. pacifica* and *T. sp. small* by Barron et al. (2009), but was

included with *T. decipiens* in a group that they termed “upwelling *Thalassiosira*”. The post ~7 cal ka diatom record of -11JC lacks the broad alternating dominance of *Thalassiosira* and *T. nitzschioides* seen in the -47JC. Rather, northeastern Pacific coastal bloom *Thalassiosira* are consistently more common in -11JC than *T. nitzschioides* with dominance seemingly increasing after ~2 cal ka. The relative abundance patterns of these two diatoms groups are more similar between -11JC and -47JC between ~10 and 7 cal ka, although peak abundance of coastal bloom *Thalassiosira* are more extreme in -47JC. Likewise, *T. nordenskiöldii*, the diatom preferring cool (summer SSTs <9°C, Ren et al., 2014), low salinity conditions that typically occur near sea ice, is relatively more common in -47JC prior to 3 cal ka than it is in -11JC, presumably reflecting the location of -47JC in the more restricted Slocum Arm fjord (Fig. 1b) where cool, fresh waters are more likely to occur.

A preliminary diatom analysis of marine sediment core EW0408-22JC (Fig. 1) off nearby Baranof Island shows some similarities with the diatom record in EW0408-47JC (C. Loofbourrow, written communication, 2014). The dominant diatom species include *Thalassiosira pacifica*, *T. nordenskiöldii*, and *Thalassionema nitzschioides*, with a key transition towards greater *T. nitzschioides* abundances observed after ~3 cal ka, which has a similar timing to that seen in 47JC’s own *T. nitzschioides* abundances.

The Holocene diatom flora of marine sediment core EW0408-85JC bears little resemblance to that of -47JC, as it is dominated by subarctic diatom *Neodenticula seminae* and *Thalassionema nitzschioides* with coastal bloom

512 *Thalassiosira* accounting for <4% of the diatom assemblage (Barron et al., 2009).
513 However, increased relative abundances (6 to 10%) of coastal bloom
514 *Thalassiosira* do occur in the -85JC record between 6 and 3 cal ka, the same
515 interval where they are seen in the -47JC record.

516

517 4.2 Comparison with the EW0408-11JC Silicoflagellate Record

518

519 Figure 5b compares the relative abundance records of the silicoflagellates
520 *Stephanocha speculum* var. *minuta*, *Stephanocha speculum* s.s., and *S.*
521 *speculum* var. *ornamentata* in EW0408-47JC and EW0408-11JC. *S. speculum*
522 var. *minuta*, which prefers cooler upwelling conditions, dominates over *S.*
523 *speculum* var. *speculum* in the -47JC record after ~3.4 cal ka, whereas the latter
524 taxon dominates in the -11JC record during approximately the same interval
525 (after ~3.8 cal ka). The relative abundance trends of these two taxa are near
526 mirror images, reflecting their dominance of silicoflagellate assemblages.
527 Presumably, these opposite patterns suggest the development of contrasting
528 paleoceanographic conditions between -11JC and -47JC core sites during the
529 late Holocene possibly with the Slocum Arm fjord site favoring increased
530 advection of GoA-derived intermediate zone waters.

531

532 4.3 Principal Component Analysis

533

Principal Component Analysis of the -47JC *Chaetoceros*-free diatom assemblage (which is restricted to taxa constituting $\geq 2\%$ of the assemblage in any one sample) resulted in seventeen variables, with three components describing 41.3% of the total variance (Table 2). The largest number of species are most clearly associated with principal component 1 (PC1), with the highest loading scores for *Coscinodiscus radiatus*, *Porosira glacialis*, *Stephanopyxis* sp., and *Thalassionema nitzschioides*, and the lowest negative scores with *Thalassiosira decipiens* and *T. nordenskioeldii*. PC2 has the highest loading scores for *T. antarctica* var. *borealis* and *Paralia sulcata*, whereas the lowest scores are for *Neodenticula seminae* and *T. angulata*. Finally, PC3 is primarily associated with a high positive loading score for *T. hyalina*, and negative loading scores for *T. oestrupii* and the benthic functional group.

When plotted downcore as a time-series, PC1, which has a strong positive loading for oceanic diatoms indicative of warmer water and higher salinity vs. strong negative loading for coastal diatoms indicative of cooler, low salinity conditions, displays mostly negative values between 10.0 and 3.2 cal ka and becoming mostly positive between 3.2 to 0.9 cal ka (Fig. 6a). The highest PC2 values, which seemingly indicate cold, lower salinity conditions and/or disturbance of shallow marginal fjord sediments, are observed between ~10.0 to 9.6, 8.8 to 6.7, and 5.7 to 4.2 cal ka. PC3 is somewhat more variable than the other components, with largely negative values between ~10.0 to 8.0 cal ka, mostly positive values between 8.0 to 3.2 cal ka, negative values between 3.2 to 1.8 cal ka, and finally somewhat positive values again from 1.8 to 0.0 cal ka.

Positive PC3 loadings possibly indicate sporadic, cool water, low salinity conditions in the fjord, whereas negative loadings may suggest more oceanic and possibly stormier conditions that might induce increased downslope transport of benthic diatoms from the fjord margins.

4.4 Diatom-Silicoflagellate Correlations

As *Stephanocha speculum* s.s and *S. speculum* var. *minuta* comprise an average of 90% (range 71-97%) of the silicoflagellate assemblage, little would be gained by performing Principal Component Analysis. Nevertheless, it is useful to make comparisons with diatom relative abundance data. *Stephanocha speculum* var. *minuta* displays a strong negative correlation with *T. nordenskiöldii* ($r = -0.54$, $p < 0.001$) and moderate positive correlation with *C. radiatus* ($r = 0.45$, $p < 0.001$), suggesting that it favors oceanic, and presumably higher salinity conditions over cold, coastal, low salinity conditions, similar to diatom PC1.

Figures 6a and b compare the downcore PCA diatom record with the record of the dominant silicoflagellate in -47JC. Diatom PC1, which appears to measure the contribution of more oceanic, higher salinity diatoms vs. colder water, lower salinity diatoms, is mostly negative until ~3.2 cal ka and remains mostly positive until ~0.9 cal ka, similar to the dominance of *S. speculum* var. *minuta* (Fig. 6b). The increased abundance of *S. speculum* var. *minuta*, a cool, upwelling proxy, during an interval dominated by a diatom assemblage indicative of warmer, higher salinity conditions is puzzling. Perhaps, *S. speculum* var.

minuta is more indicative of higher salinity conditions of the Alaskan Gyre than *S. speculum* s.s., as it dominates over the later taxon throughout the Holocene record of Alaskan Gyre core EW0408-85JC (Barron et al., 2009) and possibly is a proxy for high nutrient Alaskan Gyre waters.

PC 2, which has positive loadings for *T. antarctica* var. *borealis*, a diatom that is a proxy for cold, fresh waters that occur in the proximity of sea ice, has peak positive loadings at ~7.4 cal ka, close to an isolated ~7.6 cal ka peak in the relative abundance of the silicoflagellate *S. speculum* var. *ornamentata*, which also is indicative of cold, fresh waters similar to those found in the proximity of sea ice. Considering this change in a possible sea ice proxy, it is interesting to note that the sedimentation rate of 47JC decreases significantly from ~0.44 cm/yr prior to ~ 7.6 cal ka (~800 cm), to ~0.095 cm/yr in the younger part of the 47JC record (Fig. 2a). If winter sea ice were present along the margins of Slocum Arm prior to 7.6 cal ka, its seasonal melting may have contributed to increased sedimentation through the release of entrained sediments. Other potential mechanisms that could explain this sedimentation rate change include a mid Holocene rise in local sea level (e.g., Addison et al., 2010; Shugar et al., 2014; Carlson and Baichtal, 2015) due to loading of extensive inland ice or changes in the adjacent terrestrial landscape (e.g., Ager et al., 2010).

5. Holocene Teleconnections

602 Positive isotopic Z-scores in the $\delta^{18}\text{O}$ record of Jellybean Lake of
603 Anderson et al. (2005; 2016) (Fig. 6c), which are interpreted by Anderson et al.
604 (2016) to reflect increased advection of southern-sourced precipitation into the
605 GoA compare well with diatom factor PC1 and with increased relative
606 abundances of *S. speculum* var. *minuta*, especially between 3.2 and 1.0 cal ka. It
607 is hypothesized that this ~3.2-1.0 cal ka interval represents a period of enhanced
608 positive PDO-like expression marked by a greater contribution of warm, higher
609 salinity oceanic waters from the North Pacific Current into the eastern margin of
610 the GoA via a strengthened Alaska Current (Fig. 1). As mentioned earlier, both
611 the alkenone SST records of GoA core -85JC and ODP 1019 off northernmost
612 California (Praetorius et al., 2015) display stepwise increases in SST between 4
613 and 3 cal ka that are also consistent with positive PDO-like conditions as well as
614 with increased advection of southern sourced precipitation into the Yukon.

615 Both the Jellybean Lake $\delta^{18}\text{O}$ and -47JC records suggest the strength of
616 this subtropical teleconnection decreased at ~1.0 cal ka, coincident with the
617 Medieval Climate Anomaly. The post-1.0 cal ka diatom and silicoflagellate
618 records (Figs. 4, 6) are quite variable and less supportive of the prior trend that is
619 suggestive of enhanced positive PDO.

620 Changes in the strength of summer and winter insolation (Fig. 6d) might
621 explain the pre 3.2 cal ka parts of the -47JC diatom and silicoflagellate records
622 (Figs. 6 a, b). Insolation at 50°N (Berger and Loutre, 1991) suggests that
623 compared to the present day, colder winters and warmer summers characterized
624 the earlier part (>7.0 cal ka) of the -47JC diatom record. Thus, an increased

contribution of diatom factor PC 2, which appears to represent cool, fresh waters and the possible proximity of sea ice prior to ~7.0 cal ka is not surprising. On the other hand, the post 3.2 cal ka interval of increased PDO influence coincides with warmer winters and reduced influence of cooler, fresher waters. The middle interval (~7.0 to 3.2 cal ka) appears to be transitional between the early and later Holocene paleoceanographic conditions in Slocum Arm.

6. Summary

Diatom and silicoflagellate assemblages documented in cores EW0408-47JC, -47MC, and -46MC from the outer portion of Slocum Arm, a post-glacial fjord in southeastern Alaska, reveal a complex history of paleoclimatology and paleoceanography during the past 10,000 years. The early part of the record prior to ~6.8 cal ka contains fluctuating, mixed assemblages of diatoms indicative of coastal blooms in the northeastern Pacific (*Thalassiosira angulata*, *T. pacifica*, and *T. decipiens*), oceanic diatoms indicative of warmer, higher salinity conditions (*Thalassionema nitzschioides*, *Thalassiosira oestrupii*), and diatoms suggestive of cooler, fresher waters that could be indicative of the proximity of sea ice (*T. nordenskioeldii*). Between ~7.0 and 3.2 cal ka, the relative contribution of the coastal bloom *Thalassiosira* spp. increases at the expense of the warmer water, more oceanic diatom component, and surface water conditions in the outer portion of Slocum Arm appear to have been relatively stable. Beginning at ~3.2 cal ka, warmer water, oceanic diatoms increase at the

648 expense of the coastal bloom *Thalassiosira*, possibly signaling the onset of
649 positive PDO conditions. Increased warmer water, oceanic conditions persist
650 until ~1.0 cal ka, whereupon coastal bloom *Thalassiosira* spp. return to
651 dominance until the ~ last 100 years.

652 *Stephanocha speculum* s.s. and its cooler water form, *S. speculum* var.
653 *minuta*, dominate the Holocene silicoflagellate assemblages. The relative
654 proportions of these two taxa are roughly equal throughout the early and middle
655 parts of the -47JC record, with alternating cycles of dominance. Beginning at
656 ~3.2 cal ka and extending until ~1.2 cal ka, *S. speculum* var. *minuta* dominates
657 by 25-30% relative abundance over *S. speculum* s.s., suggesting a period of
658 increased cool water upwelling. This upwelling period coincides with the
659 increased representation of higher salinity, more oceanic diatoms such as *T.*
660 *nitzschoides*, *T. oestrupii*, and *Neodenticula seminae* in -47JC and appears to
661 represent the onset of protracted positive PDO conditions in the GoA. Warming
662 of alkenone SSTs in northern GoA core EW0408-85JC and increased
663 contribution of precipitation from a southern source in the Jellybean Lake $\delta^{18}\text{O}$
664 carbonate record are supportive of this ~3.2 cal ka shift to more positive PDO
665 conditions. The onset of high amplitude cycles in both the diatom and
666 silicoflagellate proxies at ~1.0 cal ka likely signals a decrease in the strength of
667 this PDO-like teleconnection (see Anderson et al., 2016).

668 The early part of the -47JC silicoflagellate record contains increased
669 populations of the coronatid form of *S. speculum* as well as an isolated peak
670 abundance *S. speculum* var. *ornamentata* at 7.6 cal ka that coincide with an

abrupt abundance peak in the diatom *T. nordenskiöldii*. These latter taxa both have sea ice affinities, arguing for the possible presence of sea ice in Slocum Arm.

The -47JC Holocene diatom assemblages are similar to those being studied by C. Loofbourrow (written communication, 2014) in piston core EW0408-22JC from nearby Crawfish Inlet (Fig. 1). They are markedly different, however, from those studied in Gulf of Esquibel core EW0408-11JC by Barron et al. (2009), suggesting differing paleoceanographic conditions. Silicoflagellate assemblages in -11JC display a dominance of *S. speculum* s.s. over the cooler water upwelling form *S. speculum* var. *minuta* during about the same ~3.2 to 1.0 cal ka interval where the latter form is dominant in -47JC. This dominance reversal in two core sites that are located ~300 km apart argues for the development of contrasting paleoceanographic conditions during the late Holocene. Clearly, additional studies of the Holocene paleoceanography of the southeast margin of Alaska are needed.

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704 Development Program.

707 **8. Appendices**

708

709 *8.1 List of diatom taxa recorded*

710

711 *Actinocyclus curvatulus* Janisch (illustrated in pl. 2, fig. 15)

712

713 *Actinoptychus* spp. Includes mostly *A. senarius* (Ehrenberg) Ehrenberg

714

715 *Azpeitia tabularis* (Grunow) Fryxell et Sims

716

717 *Bacterosira bathyomphala* (Cleve) Syvertsen et Hasle; synonym *B. fragilis* (Gran)

718 Gran.

719

720 *Coscinodiscus radiatus* Ehrenberg (pl. 2, fig. 16). Many of the forms have thick
721 valves that more closely resemble those of *C. marginatus*; however, they lack the
722 distinctive “skirted” margin.

723

724 *Cyclotella choctawhatcheeana* Prasad (pl. 2, fig. 14)

725

726 *Delphineis* spp.

727

728 *Fragilariopsis cylindrus* (Grunow) Krieger (pl. 2, figs. 2, 3)

729

730 *F. doliolus* (Wallich) Medlin
731
732 *F. oceanica* (Cleve) Hasle; synonym *F. grunowii* Hasle
733
734 *Hyalodiscus* spp. Includes *H. sp. cf. H. scotius* (pl. 2, fig. 1) and *H. sp. cf. H.*
735 *subtilis* (pl. 2, fig. 6).
736
737 *Neodenticula seminae* (Simonsen et Kanaya) Akiba et Yanagisawa (pl 2, fig. 4).
738
739 *Nitzschia sp. cf. N. bicapitata*
740
741 *Paralia sulcata* (Ehrenberg) Cleve and *Melosira sol* (Ehrenberg) Kützing (pl. 2,
742 fig. 9)
743
744 *Porosira glacialis* (Grunow) Jørgensen (pl. I, fig. 7, 8, 12, cf form – fig. 5). A
745 smaller form with a more clear and flatter valve face was tabulated separately as
746 (pl. 2, fig 11)
747
748 *Rhizosolenia* spp. Includes *R. styliiformis*, *R. hebetata* f. *semispina*, and other
749 unidentified *R. spp.*
750
751 *Stephanopyxis* spp. Includes *S. turris* (Arnott in Greville) Ralfs in Pritchard
752

753 *Thalassionema nitzschioides* (Grunow) Van Heurck (pl. 2, fig. 10)
 754
 755 *Thalassiosira angulata* (W. Gregory) Hasle. Smaller (<15 µm diameter) forms
 756 with regular central areolar patterns that were previously classified as *T. pacifica*
 757 (Barron et al., 2009) are classified here as *T. angulata*. (pl. 1, figs. 6, 7, 10, cf.
 758 form, fig. 14). It is possible that the form identified as *T. tenera* Proshkina-
 759 Lavrenko by Galloway et al. (2013) is the same.
 760
 761 *Thalassiosira antarctica* var. *borealis*: synonym *T. gravida* Cleve. (pl. 1, figs. 16,
 762 17, 20)
 763
 764 *Thalassiosira decipiens* (Grunow; Grunow in Van Heurck) E. Jørgensen (pl. 1,
 765 figs. 4, 5)
 766
 767 *Thalassiosira eccentrica* (Ehrenberg) Cleve (pl. 1, figs. 18, 21)
 768 Includes *T. symmetrica* Fryxell and Hasle (1972)
 769
 770 *T. hyalina* (Grunow) Gran (pl. 1, fig. 19)
 771
 772 *T. lineata* Jousé (pl. 1, fig. 8)
 773
 774 *T. nordenskiöldii* Cleve. See Hasle (1978) (pl. I, figs. 1-3)
 775

776 *T. oestrupii* (Ostenfeld) Hasle. We have chosen to retain this species in
777 *Thalassiosira* rather than transfer it to *Shionodiscus* of Alverson, Kang, et Theriot
778 (2006), because 1) Alverson et al. (2006) do not provide an argument for the
779 priority of *Shionodiscus* over *Coscinosira oestrupii* Gran 1900, and 2) we believe
780 that species with older stratigraphic records, such as *T. eccentrica* (Ehrenberg)
781 Cleve and *T. leptopus* (Grunow ex Van Heurck) Hasle et G. Fryxell, need to be
782 investigated for morphologic similarity to *T. oestrupii* before accepting the division
783 of *Thalassiosira*. We also prefer the name *T. oestrupii*, because it is widely used
784 in ocean distribution studies (Ren et al., 2014). (pl. 1, fig. 15)

785

786 *T. pacifica* Gran et Angst. Hasle et al. (1996) notes that *T. pacifica* can be
787 distinguished from *T. angulata* by its ribbed margin and more closely spaced
788 marginal processes. They note that its valve diameter ranges from 7 to 46 μm .
789 *T. sp. cf. T. pacifica* figured (pl. 1, figs 9, 12, 13).

790

791 *T. trifulta* Fryxell. See comments for *T. oestrupii*; synonym *T. latimarginata*
792 Makarova.

793

794 *T. spp.* Unidentifiable forms of *Thalassiosira*.

795

796 *Thalassiothrix longissima* Cleve et Grunow

797

798 Other planktic –Other planktic diatoms not tabulated separately.

799

800 Benthic –undifferentiated marine benthic diatoms.

801

802 Freshwater planktic (*Stephanodiscus*, *Aulacoseira*)

803

804 Freshwater benthic

805

806 Reworked –fossil diatoms that are reworked.

807

808 *8.2 List of silicoflagellate taxa*

809

810 *Dictyocha aculeata* (Lemmermann) Dumitrica 1973 s.l. (pl. 3, figs. 1, 2)

811

812 *D. sp. cf. D. aculeata* (Lemmermann) Dumitrica 1973 (pl. 3, fig. 6)

813

814 *D. stapedia* f. *spinosa* Haeckel 1887 (large form) (pl. 3, fig. 5)

815

816 Examination of a series of Pacific Coast ocean cores from Santa Barbara Basin

817 (33°N) north to the GOA (60°N) has shown that typical small specimens of *D.*

818 *stapedia* s.s. disappear from *Dictyocha* populations. Surface sediment surveys

819 show the same reduction (Poelchau, 1976). This large form of *D. stapedia* is

820 distinguished by its holotype and Poelchau's Pacific core-top study by its larger

821 size and the presence of accessory pikes on the struts. Normal small *D. stapedia*

are missing from 47JC, which supports Poelchau's observation that "in some of the northeastern samples it is occasionally the only form... present." *D. stapedia* *f. spinosa* occurs only rarely at 1-3% in the core.

Dictyocha sp.

Specimens identifiable at a generic level that are tilted and/or covered preventing species assignment. Recorded because of the general scarcity of *Dictyocha* for paleotemperature calculation comparisons.

Stephanocha (previously *Distephanus*) *florida* (Bukry) McCartney et Jordan, 2015 (pl. 3, fig. 10)

This mid- to high-latitude species was identified in the North Pacific at DSDP Sites 310, 191, 184 and 173. It is most abundant in older middle Pleistocene floras (Ling, 1975; Bukry, 1985). In -47JC it occurs as eight- and seven-spined skeletons. *Stephanocha* (*D.*) *florida* is sporadic and minor at 1-5%, occurring in both warm and cool floras, but most persistent at the top of the core. It is missing from samples where *S. speculum* var. *minuta* is greater than 60%. These distributions suggest it favors reduced upwelling.

Stephanocha (previously *Distephanus*) *octangulata* (Wailes) McCartney et Jordan, 2015 (pl. 3, fig. 14)

845

846 *Stephanocha octangulata* is a cold-water North Pacific taxon. The morphology of
847 the skeleton is well described by Poelchau (1976). It is considered a deep-water
848 taxon (E. Venrick, oral communication, 2006). In 47JC it is at low abundance (1-
849 4%) throughout the core.

850

851 *Stephanocha* (previously *Distephanus*) *quinguangella* (Bukry et Foster)
852 McCartney et Jordan, 2015 (pl. 3, fig. 12)

853

854 *S. quinguangella* is sparse (1-2%) and occurs sporadically through the core,
855 providing no paleoenvironmental trends.

856

857 *Stephanocha* (previously *Distephanus*) *speculum* var. *elongata* (Bukry)
858 McCartney et Jordan, 2015.

859

860 A minor high-latitude subspecies originally described from DSDP 303 in the
861 North Pacific. Only a single compared specimen occurred in sample -47JC1100-
862 1101 cm.

863

864 *Stephanocha* (previously *Distephanus*) *speculum* var. *minuta* (Bachmann,
865 emended by Bukry 1981) McCartney et Jordan, 2015) (pl. 3, figs. 15, 16)

866

Stephanocha speculum var. *minuta*, as emended by Bukry (1981), is a form that has an apical ring that in plan view is contiguous or overlaps the basal ring (discussed in Barron, et al, 2009). Most specimens in -47JC are small to medium sized with short spines.

Stephanocha (previously *Distephanus*) *speculum* var. *ornamentata* (Ehrenberg) McCartney et Jordan, 2015 (pl. 3, figs. 11, 13)

Regular seven-sided *S. speculum* specimens are classified as *S. speculum* var. *ornamentata* (Ehrenberg). GoA specimens have basal pikes, regular symmetry, and the same size, ornamentation and proportions as the associated *S. speculum*. The taxonomy for GoA specimens was discussed in Barron et al. (2009). Only two specimens in 47JC (180 cm) and 46MC (23.5 cm) have two dominant spines and five short spines that resemble the form of *Stephanocha speculum* var. *septenaria* (Ehrenberg) K. McCartney et R.W. Jordan.

S. speculum var. *ornamentata* has been reported as a dominant taxon in Arctic Ocean sea-ice floras (Kozo Takahashi, written communication, 2006, reported it in sea-ice areas in the Arctic Ocean at up to 71%). See Takahashi et al. (2009).

Stephanocha (previously *Distephanus*) *speculum* s.s. (Ehrenberg) McCartney et Jordan, 2015 (pl.3, figs. 3)

Stephanocha (previously *Distephanus*) *speculum* [coronatid form] (pl. 3, fig. 7)

Coronatid specimens of *S. speculum* have five or six accessory pikes on the apical ring. Normal specimens without apical pikes and those with one to four pikes are tabulated as *S. speculum*. These forms occur throughout the core at 1-3%, but notably more common in the oldest samples from -47JC, 800-801 to 1680-1681 cm (7.61 to 9.64 ka), possibly due to lower upwelling by the *minuta/speculum* ratio. Most *Stephanocha* taxa in 47JC have some specimens with a few apical pikes; these are considered normal phenotypic variation for the genus.

Stephanocha (*Distephanus*) *speculum* [pseudofibuloid form] (pl. 3, fig. 4)

Only two specimens from -47JC samples at 400-401 cm and 1680-1681 cm have pseudofibuloid apical structures where there is no apical ring formed.

Stephanocha (previously *Distephanus*) *speculum* [oblate form] (pl. 3, fig. 9)

Oblate forms of *S. speculum* have a long axis of the apical ring that is perpendicular to the major spine axis of the basal ring. These occur in -47JC 80-81cm, 240-241 cm, 480-481 cm, and 1240-1241cm. There is no correlation to cool or warm proxies.

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 1219

1220 Captions

1221

1222 Table 1 AMS ^{14}C age constraints on EW0408-47JC.

1223

1224 Table 2. Varimax-rotated loading scores of datasets included in the PCA.

1225 Loading scores >0.5 or <-0.5 are indicated in bold italics

1226

1227 Supplementary Table 1 –diatom census data for the -47JC cores.

1228

1229 Supplementary Table 2 –silicoflagellate census data for the -47JC cores.

1230

1231 Figure 1 - Study area location in the (a) Gulf of Alaska region with inset (b)

1232 showing an expanded view of the Alexander Archipelago (Southeast Alaska) and

1233 c) a further expanded view of Slocum Arm along the southwest margin of

1234 Chichagof Island. Major North Pacific surface currents are indicated in green, the

1235 Alaska Coastal Current (ACC) in white, and the generalized location of the

1236 Subarctic Front in red. Shaded-relief digital elevation model from the NOAA

1237 National Centers for Environmental Information

1238 (<http://ngdc.noaa.gov/mgg/coastal/coastal.html>) and Slocum Arm multi-beam

1239 bathymetry survey data downloaded from the Marine Geoscience Data System

1240 (survey ID EW0408; <http://www.marine-geo.org/>) and from Jaeger (2016). The

1241 location of marine cores EW0408-47JC, -85JC, -22JC, and -11JC and the

1242 Jellybean Lake record of Anderson et al. (2016) are shown.

1243

1244 Figure 2 – a) CLAM age-depth models for the composite EW0408-47JC record,
1245 calculated with both linear interpolation (black line) and LOESS smoothing (thick
1246 gray line) strategies; (b) sedimentation rate (blue line) determined using CLAM
1247 linear interpolation model; and (c) gamma-ray attenuated (GRA) wet bulk density
1248 record (light gray line; red line is 5 point – 3 pass moving average smooth). 95%
1249 confidence intervals are indicated on both a and b.

1250

1251 Figure 3 – Downcore diatom record of EW0408-47JC showing ecological groups
1252 plotted against inferred ages from Figure 2. Data are based on *Chaetoceros*-free
1253 counts; * *Chaetoceros* percent refers to ratio to other diatoms. Dashed lines at
1254 3.2 and 6.8 cal ka indicate times of assemblage change (see text).

1255

1256 Figure 4 - Downcore silicoflagellate record of EW0408-47JC showing ecological
1257 groups (see text) plotted against inferred ages from Figure 2. Dashed lines at
1258 3.2 and 6.8 cal ka indicate times of diatom assemblage change (see text).

1259

1260 Figure 5 –Comparison of the EW0408-47JC and EW0408-11JC diatom and
1261 silicoflagellate records. Coastal bloom *Thalassiosira* include *T. angulata*, *T.*
1262 *pacifica*, and *T. decipiens* of this report. Dashed lines at 3.2 and 6.8 cal ka
1263 indicate times of diatom assemblage change in -47JC (see text).

1264

1265 Figure 6 –Comparison of a) diatom PC1, PC2, and PC3 scores in -47JC, b) the
1266 dominance record of the silicoflagellate *Stephanocha speculum* var. *minuta* in -
1267 47JC, c) Anderson et al.'s (2016) Jellybean Lake $\delta^{18}\text{O}$ record (positive values =
1268 precipitation from a southern source), and d) the percent deviation of solar
1269 insolation from average Holocene values at 50°N (Berger and Loutre, 1991).
1270 Dashed lines at 3.2 and 6.8 cal ka indicate times of diatom assemblage change
1271 (see text).

1272 **11 Plate Captions**

1273

1274 Plate 1 Diatoms

1275

1276 1, 2, 3 *Thalassiosira nordenskiöldii*, 1 = -47JC, 1240 cm; 2, 3 = -47JC, 800 cm

1277 4, 5 *Thalassiosira decipiens*, 4 = -47JC, 1240 cm; 5 = -47JC, 560 cm

1278 6, 7, 10 *Thalassiosira angulata*, 6 = -47JC, 620 cm; 7, 10 = -47JC, 160 cm;

1279 8 *Thalassiosira lineata* -47JC, 1240 cm

1280 9, 12, 13 *Thalassiosira* sp. cf. *T. pacifica*, 9 = -47JC, 620 cm; 12 = -47JC, 160

1281 cm; 13 = -47JC, 1240 cm

1282 11 *Thalassiosira trifulta*, -47JC, 1240 cm

1283 14 *Thalassiosira* sp. cf. *T. angulata*, -47JC, 160 cm

1284 15 *Thalassiosira oestrupii* var. *oestrupii*, = -47JC, 620 cm;

1285 16, 17, 20 *Thalassiosira antarctica* var. *borealis*, 16 = -47JC, 80 cm; 17 = -47JC,

1286 560 cm; 20 = -47JC, 1240 cm.

1287 18, 21 *Thalassiosira eccentrica*, 18 = -47JC, 1240 cm; 21 = -47JC, 1380 cm.

1288 19 *Thalassiosira hyalina*, -47JC, 660 cm

1289

1290 Plate 2 Diatoms

1291

1292 1 *Hyalodiscus* sp. cf. *H. scotius*, -47JC, 800 cm

1293 2, 3 *Fragilariopsis cylindrus*, 2 = -47JC, 700 cm; 3 = -47JC, 560 cm

1294 4 *Neodenticula seminae*, -47JC, 800 cm

- 1295 5 *Porosira* sp. cf. *P. glacialis* (resting spore), -47JC, 160 cm
- 1296 6 *Hyalodiscus* sp. cf. *H. subtilus*, -47JC, 80 cm
- 1297 7, 8, 12 *Porosira glacialis* (resting spore), 7, 8 (less dense form), -47JC, 660 cm;
- 1298 12 = -47JC, 160 cm
- 1299 9 *Melosira sol*, -47JC, 560 cm
- 1300 10 *Thalassionema nitzschioides*, -47JC, 800 cm
- 1301 11 *Porosira* sp. cf. *P. glacialis*? (resting spore) (small, clear form), 11a, high focus,
- 1302 11b, low focus, -47JC, 80 cm
- 1303 13 *Stephanodiscus* sp., 13a, high focus, 13b, low focus, -47JC, 1380 cm
- 1304 14 *Cyclotella choctawhatcheeana*, -47JC, 660 cm
- 1305 15 *Actinocyclus curvatulus*, -47JC, 560 cm
- 1306 16 *Coscinodiscus radiatus* -47JC, 620 cm
- 1307
- 1308 Plate 3 Silicoflagellates
- 1309
- 1310 1, 2 *Dictyocha aculeata*, 1 = -47JC, 1680 cm; 2 = -47JC, 400 cm.
- 1311 3 *Stephanocha (Distephanus) speculum* s.s., -47JC, 800 cm, a = low; b = high
- 1312 focus.
- 1313 4 *Stephanocha (Distephanus) speculum* [pseuofibuloid form], -47JC, 400 cm
- 1314 5 *Dictyocha stapedia* f. *spinosa*, -47JC, 800 cm, a, high; b, low focus
- 1315 6 *Dictyocha* sp. cf. *D. aculeata*, -47JC, 160 cm
- 1316 7 *Stephanocha (Distephanus) speculum* [coronatid form], -47JC, 2 cm, a, high; b,
- 1317 low focus

- 1318 8 *Stephanocha (Distephanus) speculum* var. *ornamentata*, -47JC, 800 cm, a,
1319 high; b, low focus
- 1320 9 *Stephanocha (Distephanus) speculum* [oblate form], -47JC, 1240 cm, a, low; b,
1321 high focus
- 1322 10 *Stephanocha (Distephanus) florida*, -47JC, 280 cm
- 1323 11 *Stephanocha (Distephanus) speculum* var. *ornamentata*, -47JC, 360 cm
- 1324 12 *Stephanocha (Distephanus) quinquangella*, -47JC, 764 cm
- 1325 13 *Stephanocha (Distephanus) speculum* var. *ornamentata*, -47JC, 1630 cm
- 1326 14 *Stephanocha (Distephanus) octangulata*, -47JC, 1240 cm
- 1327 15, 16 *Stephanocha (Distephanus) speculum* var. *minuta*, 15 = -47JC, 320 cm;
1328 16 = -47JC, 138 cm
- 1329

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Table 1

Table 1: AMS ^{14}C age constraints on EW0408-47JC.

Sample depth (cm)	Corrected depth (cm bsf)*	Material	Reported ^{14}C age (yrs BP) [#]	^{14}C error (yrs)	2 σ calibrated range (cal yrs BP) [†]	AMS ^{14}C laboratory	Sample ID number	Reference
0	0	Sediment-water interface (AD 2004)	-	-	-54		-	
190	232	Bivalve	3315	30	2645 to 2913		WW-8165	
398	440	Bivalve	4825	30	4517 to 4820		WW-8166	
557	599	Bivalve	6380	35	6317 to 6618		WW-8167	
646	688	Mt. Edgecumbe Tephra	5760	70	6407 to 6725		-	Addison et al., 2010
728	770	Wood fragment	6685	30	7501 to 7607		WW-6079	Addison et al., 2010
834	876	Bivalve	7525	30	7552 to 7786		WW-8168	
907	949	Bivalve	7760	35	7743 to 8005		WW-8169	
1015	1057	Bivalve	8005	30	7994 to 8280		WW-8170	
1128	1170	Bivalve [‡]	8395	30	8380 to 8662		WW-6065	Addison et al., 2010
1128	1170	Wood fragment	7660	30	8400 to 8537		WW-6080	
1273	1315	Bivalve	8665	30	8677 to 9057		WW-8171	
1337	1379	Bivalve	8830	35	8974 to 9289		WW-8172	
1480	1522	Bivalve	9000	40	9147 to 9467		WW-8173	
1615	1657	Bivalve	9155	45	9327 to 9630		WW-8174	
1780	1822	Plant material	8865	50	9746 to 10176		WW-6104	Addison et al., 2010

* : +42 cm offset to align piston core with surface multicore and intervening trigger core based on geophysical properties.

: Two paired terrestrial-marine AMS ^{14}C samples at EW0408-33JC (Addison et al., submitted) indicate local mean marine reservoir effect of 743 $\pm$ 6 years at 2 σ . Praetorius et al. (2015) use a MRC = 735 $\pm$ 50 yrs for nearby EW0408-26JC. A single paired terrestrial-marine AMS ^{14}C sample in EW0408-47JC suggests an MRC of 735 yrs, consistent with both of these estimates, so an MRC of 735 $\pm$ 50 yrs was applied to all marine carbonate-based ^{14}C samples in EW0408-47JC [e.g., ΔR = 335 $\pm$ 50 yrs].

† : IntCal13 calibration curve used for terrestrially-derived macrofossil dates, while Marine13 curve used for all bivalve dates with ΔR = 335 $\pm$ 50 yrs.

‡ : Not used in age-model calculations due to co-occurrence of wood fragment from same depth interval.

Table 2

Species and/or functional group (natural-log transformed)	n	PCA loading scores		
		PC1	PC2	PC3
<i>Actinocyclus curvatus</i>	44	.476	-.237	.379
<i>Bacteriosira bathyomphala</i>	37	.178	.375	.459
<i>Coscinodiscus radiatus</i>	46	.624	-.104	.290
<i>Neodenticula seminae</i>	46	.086	-.762	-.025
<i>Porosira glacialis</i>	43	.639	.259	.098
<i>Stephanopyxis</i> spp.	43	.567	.406	-.192
<i>Thalassionema nitzschioides</i>	46	.513	-.169	-.120
<i>Thalassiosira angulata</i>	46	-.405	-.525	.409
<i>T. decipiens</i>	44	-.571	.025	.183
<i>T. eccentrica</i>	46	-.041	-.010	-.473
<i>T. antarctica</i> var. <i>borelais</i>	40	-.354	.600	-.219
<i>T. hyalina</i>	44	-.269	.161	.599
<i>T. nordenskiöldii</i>	46	-.546	.266	-.003
<i>T. oestrupii</i>	46	-.130	.065	-.593
<i>T. pacifica</i>	44	-.367	.138	-.135
<i>Paralia sulcata</i>	43	-.176	.553	.079
Benthic diatom functional group	46	.044	.180	-.597
PCA variance described		16.6%	12.6%	12.1%