Quaternary Research 82 (2014) 73–84

Contents lists available at ScienceDirect

Quaternary Research

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

Holocene storminess inferred from sediments of two lakes on Adak Island, Alaska

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ARTICLE INFO

Article history:
Received 28 June 2013
Available online 13 April 2014

Keywords:
Holocene storminess
Biogenic silica
Inferred chlorophyll-*a*
Adak Island
Lake sediments

ABSTRACT

The abundance of sedimentary organic material from two lakes was used to infer past Holocene storminess on Adak Island where frequent storms generate abundant rainfall and extensive cloud cover. Andrew and Heart Lakes are located 10 km apart; their contrasting physical characteristics cause the sedimentary organic matter to respond differently to storms. Their records were synchronized using correlated tephra beds. Sedimentation rates increased between 4.0 and 3.5 ka in both lakes. Over the instrumental period, Andrew Lake biogenic-silica content (BSi) is most strongly correlated with winter sunlight availability, which influences photosynthetic production, and river input, which influences the dilution of BSi by mineral matter. Heart Lake BSi is likely affected by wind-driven remobilization of sediment, as suggested by correlations among BSi, the North Pacific Index, and winter storminess. The results indicate relatively stormy conditions from 9.6 to 4.0 ka, followed by drying between 4.0 and 2.7 ka, with the driest conditions from 2.7 to 1.5 ka. The stormiest period was between AD 500 and 1200, then drying from 1150 to 1500 and more variable until 1850. This record of Holocene storminess fills a major gap at the center of action for North Pacific wintertime climate.

Introduction

The central Aleutian Islands are situated at the center of action for North Pacific wintertime climate. The Aleutian Low pressure system is one of the large-scale features of ocean–atmospheric circulation in the Northern Hemisphere. It steers storms that deliver precipitation to much of western North America. When the Aleutian Low is strong, it shifts eastward and directs storms across the North Pacific and into the Gulf of Alaska. When the Aleutian Low is weak, storm tracks move northeastward across the western Aleutian Islands and are more scattered (Rodionov et al., 2005). This paper presents the first lacustrine proxy climate record for the central Aleutian Islands, filling a large gap in the network of sites that is needed to understand the long-term behavior of the Aleutian Low pressure system over its huge area of influence. Since 1950 the Aleutian Low has strengthened, and it is projected to further intensify in most climate models (Salathé, 2006).

In this study, we investigate biological proxies of past meteorological variability, including the effect of storms on lacustrine sedimentation. Storms in the central Aleutian Islands are most frequent in the fall and winter (Rodionov et al., 2005). Storms on Adak Island bring intense rainfall (defined here as greater than 19 mm falling in a day) and extensive cloud cover (100% cover), which influence sedimentation and biological productivity. Intense rain that falls during winter, when vegetation cover is reduced, likely results in overland flow and sediment transport over hillslopes and in stream channels. Additionally, extensive cloud cover diminishes sunlight-induced primary production in lakes. This study examines correlations between winter-season (DJF) storminess and biogenic silica, organic matter, and chlorophyll-*a* content. These biological components of lake sediment reflect past production of organic materials. We used a paired-lake approach to investigate how sedimentation and the abundance of organic material in two lakes with contrasting settings respond to changes in storminess. Several recent paleolimnologic studies stress the importance of using paired-lake studies to gain a better understanding of the processes that influence sedimentation and proxy response to climate change (recent examples include Anderson et al., 2012; Balascio and Bradley, 2012; Dugan et al., 2012; Munroe, 2012). A larger lake (8.4 km^2 and 26 m deep) and a smaller lake (0.25 km^2 and 8 m deep) were compared to identify local watershed processes that might influence the proxies. The sedimentary sequences from the two lakes have been tightly correlated using multiple tephra beds in each of the analyzed cores (Krawiec, 2013; Krawiec et al., 2013).

Study area and climate setting

Adak Island is situated in the central Aleutian Islands, which separate the Bering Sea from the North Pacific (Fig. 1). South of Adak Island, the Alaska Stream flows westward and circulates up through the Aleutian

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http://dx.doi.org/10.1016/j.yqres.2014.02.007
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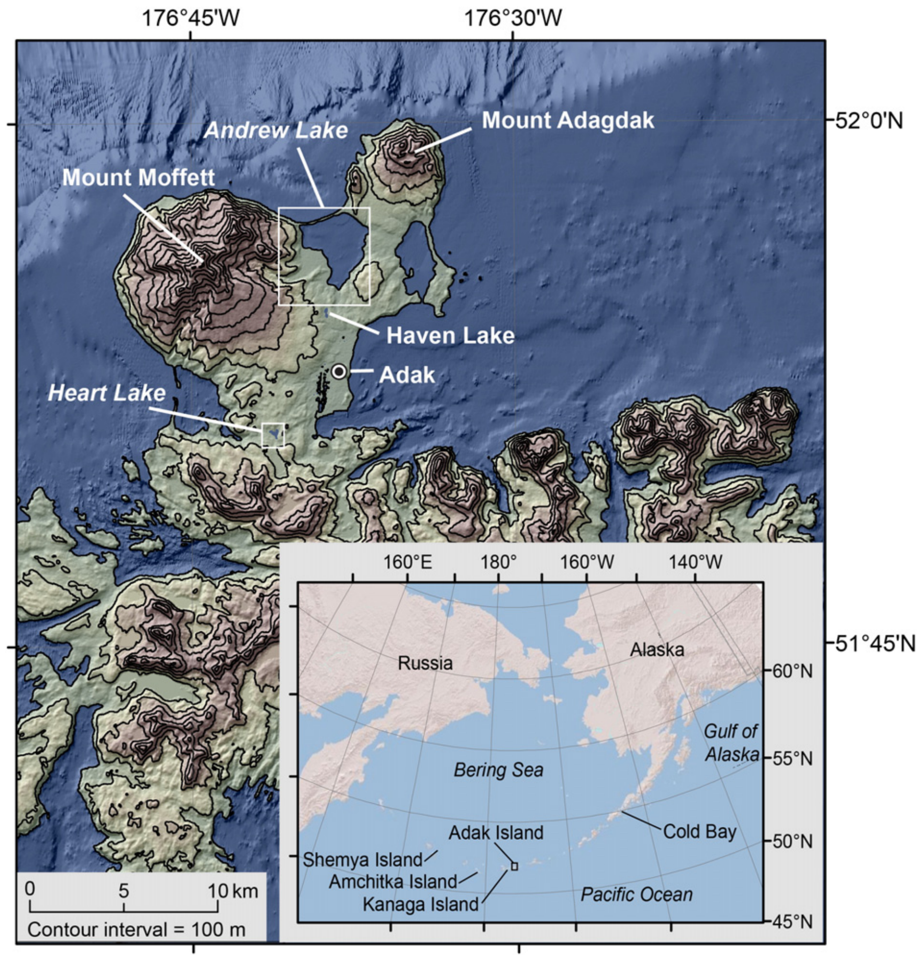

Figure 1. Northern part of Adak Island showing locations of Heart and Andrew Lakes and other places mentioned in the text. White boxes indicate map areas in Fig. 2. The base map is from a 1/9 arc-second (30 m/pixel) digital elevation model from the National Geophysical Data Center (Carignan et al., 2009).

passes and into the eddying Bering Slope Current or back eastward as the Aleutian North Slope Current (Stabeno et al., 2005). Atmospheric circulation is dominated by the Aleutian Low pressure system, which strengthens in the winter and largely dissipates during the summer. When the Aleutian Low is weaker, storms tend to track over the central Aleutian Islands; when the pressure system is stronger, storms tend to track south of the Aleutians and into the Gulf of Alaska (Rodionov et al., 2005).

Andrew and Heart Lakes differ in their setting, morphology, and catchment characteristics (Table 1; Fig. 2). Andrew Lake is a large deep lake near the north coast of the island. Mt. Moffet constitutes a significant portion of Andrew Lake's catchment, and it seems to have supported Holocene alpine glaciers. A low-relief bouldery barrier ranging from 2 to 10 m asl separates the lake from the Bering Sea. A collaborative study includes water isotope data from Andrew Lake showing values falling along the meteoric water line, which suggests that the lake is not highly influenced by seawater (Vaillencourt, 2013). Andrew Lake has a man-made outflow across the boulder barrier to the Bering Sea and many small inflow streams off Mt. Moffet and Mt. Adagak, including an inflow stream from upstream lakes to the south. Heart Lake is a small shallow lake located 10 km southwest of Andrew Lake in low-relief, rolling hills between the mountainous terrain to the south and north. Its catchment includes a Pleistocene cirque to the south and two larger upstream lakes. Heart Lake has both an inflow and outflow stream.

Adak Island has a maritime climate with frequent fog and light rain in the summer (May through July) and frequent storms from October through December (Fig. 3). Strong winds (annual average of 24 km/h) and cloud cover (90% annual average) are persistent throughout the year. Of the 1370 mm/yr average precipitation, 33% falls during an average of 16 storm events per year, each delivering at least 19 mm in one day. Annual temperatures are highly moderated by the oceanic setting and vary little annually. Average monthly temperatures range from 10.7°C in August, to −0.1°C in January. Winter temperatures are normally too high for persistent lake ice to develop, especially on lower-elevation lakes. At Adak, only 27% of days between December and February have high temperatures that exceed 2°C.

Methods

Core recovery

Sediment cores were recovered from Heart and Andrew Lakes in the summers of 2009 and 2010. Cores were taken from two sites at each lake. Surface cores with an intact sediment–water interface were taken at each site with a gravity corer. The undisturbed surface was preserved with absorbent polymer powder and floral foam for transport. Cores from Site 1 at both lakes were chosen for analysis based on their stratigraphic integrity and length. In Andrew Lake, Site 1 is located on the gentle bathymetric slope on the south side of the lake. In Heart Lake, Site 1 is located a few meters southeast of the deepest point (Fig. 2).

Geochronology

The age models for the two lake sediment cores are presented in a study devoted to the tephrostratigraphy and radiometric dating of the