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A multi-proxy reconstruction of environmental change spanning the last 37,000 years from Burial Lake, Arctic Alaska

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ABSTRACT

Sediment cores from Burial Lake located in the western Brooks Range in Arctic Alaska record paleoenvironmental changes that span the last 37,000 calendar years before present (cal yr BP). We identified four distinct lithologic subunits based on physical properties (dry bulk density, magnetic susceptibility), sediment composition, and geochemical proxies (organic matter, biogenic silica, C/N, organic matter $\delta^{13}C$ and $\delta^{15}N$, and elemental data from scanning X-ray fluorescence). The multi-proxy approach and relatively high temporal resolution (at multi-decadal to centennial time scales) of our proxy analysis, compared with previous studies of intermediate water depth cores from Burial Lake, provide new insights into the paleoenvironmental history of the region spanning the period prior to the Last Glacial Maximum. Relatively high lake-levels and gradually decreasing in-lake and terrestrial productivity occur during the mid-Wisconsin interstadial from 37,200 to 29,600 cal yr BP. The subsequent period is defined by falling and lower lake-levels with decreasing effective-moisture, windier conditions, and sustained low aquatic productivity throughout the LGM between 29,600 and 19,600 cal yr BP. The last deglaciation that commenced by 19,600 cal yr BP is characterized by gradual changes in several sediment physical and geochemical proxies, including increasing C/N ratios and terrestrial productivity, decreasing magnetic susceptibility and clastic sediment flux, along with rising and relatively higher lake-levels. A decrease in aeolian activity after 16,500 cal yr BP is inferred from the appearance of fine (very fine sandy silt) sediment, compared to coarse sediments through the LGM and last deglaciation. The highest levels of terrestrial inputs along with increasing and variable aquatic productivity occur during the Lateglacial to early Holocene interval between 16,500 and 8800 cal yr BP. The absence of multi-proxy evidence for a strong climatic reversal during the Younger Dryas from Burial Lake sediments contrasts with some paleorecords showing cooler temperatures and/or dry conditions in northern Alaska at this time. Peak levels of sediment organic content and terrestrial productivity at Burial Lake between 10,500 and 9900 cal yr BP coincide with the early Holocene summer insolation maxima, which likely represents summertime warming and an enhanced flux of watershed derived organic matter from permafrost degradation. The remainder of the Holocene (since 8800 cal yr BP) at Burial Lake is characterized by relatively high and stable lake levels, landscape stabilization, and relatively high and variable levels of aquatic productivity.

1. Introduction

Recent climate change in the Alaskan Arctic is a having a profound effect on aquatic and terrestrial ecosystems, the surface hydrology of lakes and ponds, and the stability of permafrost landscapes. For example, warming temperatures between A.D. 1990 and 2009 coincide with an increase in the abundance of shrubs and terrestrial productivity in tundra landscapes across Arctic Alaska (Swanson, 2010). Accelerated permafrost degradation and thaw slumping observed in the Noatak Basin have been attributed to general climate warming and shifting trends in the seasonality of weather (Balser et al., 2014). Further, an ~30% decrease in pond and

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thaw lake surface area on the Alaskan North Slope between A.D. 1948 and 2013 corresponded with increases in air temperature and permafrost active layer thickness (Andresen and Lougheed, 2015). The drying and disappearance of these tundra ponds near Barrow, Alaska has been linked with increased evaporation from warming, permafrost degradation, and increased emergent vegetation. Additional changes include a decrease in lake ice cover duration by 24 days between A.D. 1950 and 2011 on the Alaskan North Slope (Surdu et al., 2014) and shrinking sea-ice cover in the adjacent Chukchi Sea (Wendler et al., 2014). Understanding the significance of these terrestrial ecosystem changes and of natural climate variability in the Alaskan Arctic requires a longer-term perspective than is provided by instrumental weather records and satellite observations, so that they might be placed in an appropriate context.

The late-Quaternary climatic and environmental history of the Arctic Noatak Basin in the western Brooks Range in Alaska, confined by the Delong Mountains to the north and Baird Mountains to the south, is primarily based on extensive surficial mapping and analysis of alluvial, lacustrine, and glacial deposits (Hamilton and Van Etten, 1984; Hamilton et al., 1987; Hamilton, 2001, 2010). Alluvial deposits along Noatak River and tributaries show extensive aggradation during stadial periods and channel incision, floodplain construction, and soil formation during interstadial periods (Hamilton, 2010). Glaciolacustrine and ice-contact glacial deposits are scattered throughout the basin and provide evidence for large proglacial lakes and periods of moraine construction spanning the middle Pleistocene to the Last Glacial Maximum (LGM) or late Wisconsin (Hamilton and Van Etten, 1984; Hamilton et al., 1987). For instance, bracketing radiocarbon ages constrain the LGM to between 35 and 13.6 ka ^{14}C years in the western Noatak Basin (Hamilton, 2010). Floodplain aggradation on Noatak River ended by or shortly after 13.6 ka ^{14}C years and was followed by Holocene channel incision and down-cutting (Hamilton, 2001). Further evidence for climatic and environmental changes in the Noatak Basin are inferred from palynological analysis of sediment cores from several lakes including Kaiyak (Anderson, 1985), Niliq (Anderson, 1988), and Feniak (Eisner and Colinvaux, 1992) (all shown in Fig. 1) along with analysis of fossil beetle assemblages to interpret temperatures (Elias et al., 1999; Elias, 2000). More recently, core-transect and multi-proxy analysis (pollen, organic geochemical proxies, and chironomids) of intermediate water depth (7.9 m) cores from Burial Lake (Fig. 1) reconstructed changes in relative lake-levels, vegetational patterns, and summer temperatures across the last 40,000 years (Kurek et al., 2009; Abbott et al., 2010), however, an unconformity and missing sediments spanning the LGM limited the scope of these studies. Collectively, the previous studies and environmental interpretations are limited by the complex and discontinuous nature of surficial stratigraphic deposits (Elias, 2000; Hamilton, 2001), bulk sediment radiocarbon dating and emphasis on pollen analysis to assess environmental changes (Anderson, 1985, 1988; Eisner and Colinvaux, 1992), and the coarse resolution of proxy analysis and missing sediments through the LGM (Kurek et al., 2009; Abbott et al., 2010).

The primary objective of this study was to investigate climatic and environmental changes from the interstadial period prior to the LGM to the present from multi-proxy analysis of newly recovered Burial Lake depocenter cores (21.5 m water depth). In this study, we analyzed multiple physical and geochemical proxies (including dry bulk density, organic matter, biogenic silica, carbon to nitrogen mass ratios (C/N), stable carbon and nitrogen isotopes (δ^{13}C and δ^{15}N) of organic matter, and elemental abundances via scanning X-ray fluorescence) along with sediment description and used Accelerator Mass Spectrometry (AMS) radiocarbon dating of wood, seeds, and plant macrofossils to establish age control. Proxies in this study were analyzed at much higher temporal resolution than previous works at Burial Lake to investigate multi-decadal to century scale variations in environmental conditions. Comparison with a newly developed environmental magnetic record from the same sediment cores (Dorfman et al., in this issue), other regional glacial and lacustrine records from northwest Alaska, along with nearby marine records provides an assessment and new synthesis of regional climatic change in the western Brooks Range during the late Quaternary.

2. Site location and regional setting

Burial Lake (68.43°N, 159.17°W; 460 m ASL) is located in the upper Anisak River drainage within the Noatak Basin in the northwestern Brooks Range, Alaska (Fig. 1). The surface area of Burial Lake is approximately circular (0.8 km^2) and has a maximum water depth of 21.5 m. The lake is situated on a subtle topographic high between Setting Sun Creek to the west and a small tributary to the east (Fig. 1) that drains to Anisak River and eventually Noatak River. The surrounding catchment is small (3.3 km^2) with steep (3–5 m high) slopes along much of the lake's shoreline that transition to a low-relief plateau. The lake receives inflow from several ephemeral gullies along the northern shoreline and contains a small outlet stream at the southwest shoreline. Burial Lake is oligotrophic and a hydrologically open system. Vegetation is low-arctic tundra, dominated by sedges, *Salix*, shrub-*Betula*, and *Alnus crispa*, with sparse stands of *Populus balsamifera* found in river valleys and along creek beds (Abbott et al., 2010). Tree-line for the nearest *Picea glauca* (spruce) forest lies ~100 km to the west, and also encroaches on the Basin from the south.

The lake is located in the Aniuk Lowland sub-province within the Noatak Lowland physiographic province, an irregular rolling plain that slopes gradually to the south (Wahrhaftig, 1965). The Delong Mountains flank the lake and catchment to the north and consist of a series of rugged glaciated ridges with altitudes >1250 m, while the lower altitude (>900 m) Iggiruk Mountains are located to the south. Bedrock geology in the catchment consists of Mississippian age carbonate and clastic sedimentary rocks, consisting of limestone and subordinate shale, chert, and dolomite (Grybeck et al., 1977). Surficial geology in the catchment is mapped as Itkillik I age (early Wisconsin, Marine Isotope Stage 4) lake deposits, Holocene to late Pleistocene age solifluction deposits, and silt-covered (loess) bedrock (Hamilton, 2010). The catchment and surrounding region is underlain by continuous permafrost and ground ice is mapped as low or <10% volume (Jorgenson et al., 2008). During the Sagavanirktok River glaciation (middle Pleistocene age), alpine glaciers originating in the Delong Mountains scoured the landscape and dammed local drainage, forming the lake basin (Hamilton, 2003a). Subsequent glacier advances in the Noatak Basin were less extensive, including during early Wisconsin (Itkillik I) and late Wisconsin (Itkillik II) advances (Hamilton, 2001), and glaciers did not extend across the lake and adjacent terrain during the LGM. During middle and late Pleistocene glacial periods, alpine glaciers emanating from the Delong Mountains extended into the lowlands and repeatedly dammed Noatak River forming Glacial Lake Noatak (Hamilton and Van Etten, 1984). While the lake was not covered by Itkillik II age (LGM) lacustrine deposits, the lower Anisak River valley and western Noatak Basin were inundated by Glacial Lake Noatak (Hamilton, 2010). During the LGM, alpine glacial erosion resulted in outwash deposition and extensive floodplain aggradation in the Noatak Basin (Hamilton, 2001).

The regional climate in the Noatak Basin is characterized by long cold winters and short cool summers. Bieniek et al. (2012) place the upper Noatak Basin within the North Slope climate division, a region defined by arid conditions (maximum precipitation of <5 cm in the wettest summer month) with seasonal average temperatures