Palaeogeography, Palaeoclimatology, Palaeoecology 331–332 (2012) 90–103

Contents lists available at SciVerse ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

# Holocene seasonal variability inferred from multiple proxy records from Crevice Lake, Yellowstone National Park, USA

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ARTICLE INFO

*Article history:*
Received 10 August 2011
Received in revised form 28 February 2012
Accepted 2 March 2012
Available online 11 March 2012

*Keywords:*
Yellowstone National Park
Varved sediments
Holocene
Pollen
Charcoal
Diatoms
Inorganic geochemistry
Mineralogy
Isotope geochemistry
Summer-wet climate

ABSTRACT

A 9400-yr-old record from Crevice Lake, a semi-closed alkaline lake in northern Yellowstone National Park, was analyzed for pollen, charcoal, geochemistry, mineralogy, diatoms, and stable isotopes to develop a nuanced understanding of Holocene environmental history in a region of northern Rocky Mountains that receives both summer and winter precipitation. The limited surface area, conical bathymetry, and deep water (>31 m) of Crevice Lake create oxygen-deficient conditions in the hypolimnion and preserve annually laminated sediment (varves) for much of the record. Pollen data indicate that the watershed supported a closed *Pinus*-dominated forest and low fire frequency prior to 8200 cal yr BP, followed by open parkland until 2600 cal yr BP, and open mixed-conifer forest thereafter. Fire activity shifted from infrequent stand-replacing fires initially to frequent surface fires in the middle Holocene and stand-replacing events in recent centuries. Low values of $\delta^{18}O$ suggest high winter precipitation in the early Holocene, followed by steadily drier conditions after 8500 cal yr BP. Carbonate-rich sediments before 5000 cal yr BP imply warmer summer conditions than after 5000 cal yr BP. High values of molybdenum (Mo), uranium (U), and sulfur (S) indicate anoxic bottom-waters before 8000 cal yr BP, between 4400 and 3900 cal yr BP, and after 2400 cal yr BP. The diatom record indicates extensive water-column mixing in spring and early summer through much of the Holocene, but a period between 2200 and 800 cal yr BP had strong summer stratification, phosphate limitation, and oxygen-deficient bottom waters. Together, the proxy data suggest wet winters, protracted springs, and warm effectively wet summers in the early Holocene and less snowpack, cool springs, warm dry summers in the middle Holocene. In the late Holocene, the region and lake experienced extreme changes in winter, spring, and summer conditions, with particularly short springs and dry summers and winters during the Roman Warm Period (~2000 cal yr BP) and Medieval Climate Anomaly (1200–800 cal yr BP). Long springs and mild summers occurred during the Little Ice Age, and these conditions persist to the present. Although the proxy data indicate effectively wet summer conditions in the early Holocene and drier conditions in the middle and late Holocene, none point specifically to changes in summer precipitation as the cause. Instead, summer conditions were governed by multi-seasonal controls on effective moisture that operated over multiple time scales.



## 1. Introduction

The present climate of the northern Rocky Mountains previously has been broadly divided into two precipitation regimes, one that is strongly influenced by the northeast Pacific subtropical high-pressure system in summer, and one with substantially more summer precipitation as a result of monsoonal circulation coming from the Gulf of Mexico and the subtropical Pacific (Mock, 1996). These regimes have been referred to as summer-dry and summer-wet, recognizing that winter and spring seasons contribute most of the annual precipitation received in the region (Whitlock and Bartlein, 1993). The geographic pattern of these precipitation regimes is clear at a continental scale, but spatial heterogeneity of current and past climate variations in mountainous regions is striking. Whitlock and Bartlein (1993) postulated that the location of so-called summer-

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doi:10.1016/j.palaeo.2012.03.001

wet and summer-dry regimes in the northern Rocky Mountains is and has been constrained by topography. They argue that the regimes were both intensified in the early Holocene as a result of the amplification of the seasonal cycle of insolation then. In summer-dry regions, increased summer insolation strengthened the northeastern Pacific subtropical high-pressure system, suppressing summer precipitation, whereas summer-wet regions became wetter than today as a result of stronger monsoonal circulation in the early Holocene. Thus, summer-wet regions were wetter in the early Holocene than at present and summer-dry regions were drier than at present, but Whitlock and Bartlein (1993) suggest their relative geographic location (unlike their intensity) has not changed substantially.

Evaluation of the summer-wet/summer-dry hypotheses has rested primarily on pollen and charcoal data. Here, we provide further examination of the hypothesis by comparing a suite of climatic and environmental proxy measurements from a varved-sediment core from Crevice Lake in northern Yellowstone National Park (YNP) (45.000 N, 110.578 W, elev. 1684 m). These measurements include proxies sensitive to winter snowpack and period of ice melt (stable isotopes of endogenic carbonate); spring water-column stratification and oxygen deficiency (diatoms and redox sensitive elements); organic productivity (diatoms, organic carbon, biogenic silica); terrestrial changes (pollen, charcoal, detrital influx); and hydroclimatic variability (stable oxygen isotopes). Our objective was to describe the various datasets collected at Crevice Lake and provide mutually consistent interpretations of the multiple indicators, recognizing that individual datasets may have alternative explanations. The Crevice Lake reconstruction is compared with other records from YNP and the northern Rocky Mountains to better understand regional environmental change during the Holocene.

## 2. Site description

Crevice Lake is a closed, groundwater-fed lake on the floor of the Black Canyon of the Yellowstone River in northern YNP (Fig. 1), located inside the limits of the late Pleistocene Greater Yellowstone glacial system and more than 65 km up-valley from the Pinedale terminal moraines (Pierce, 1979). Surrounding bouldery deposits with sandy

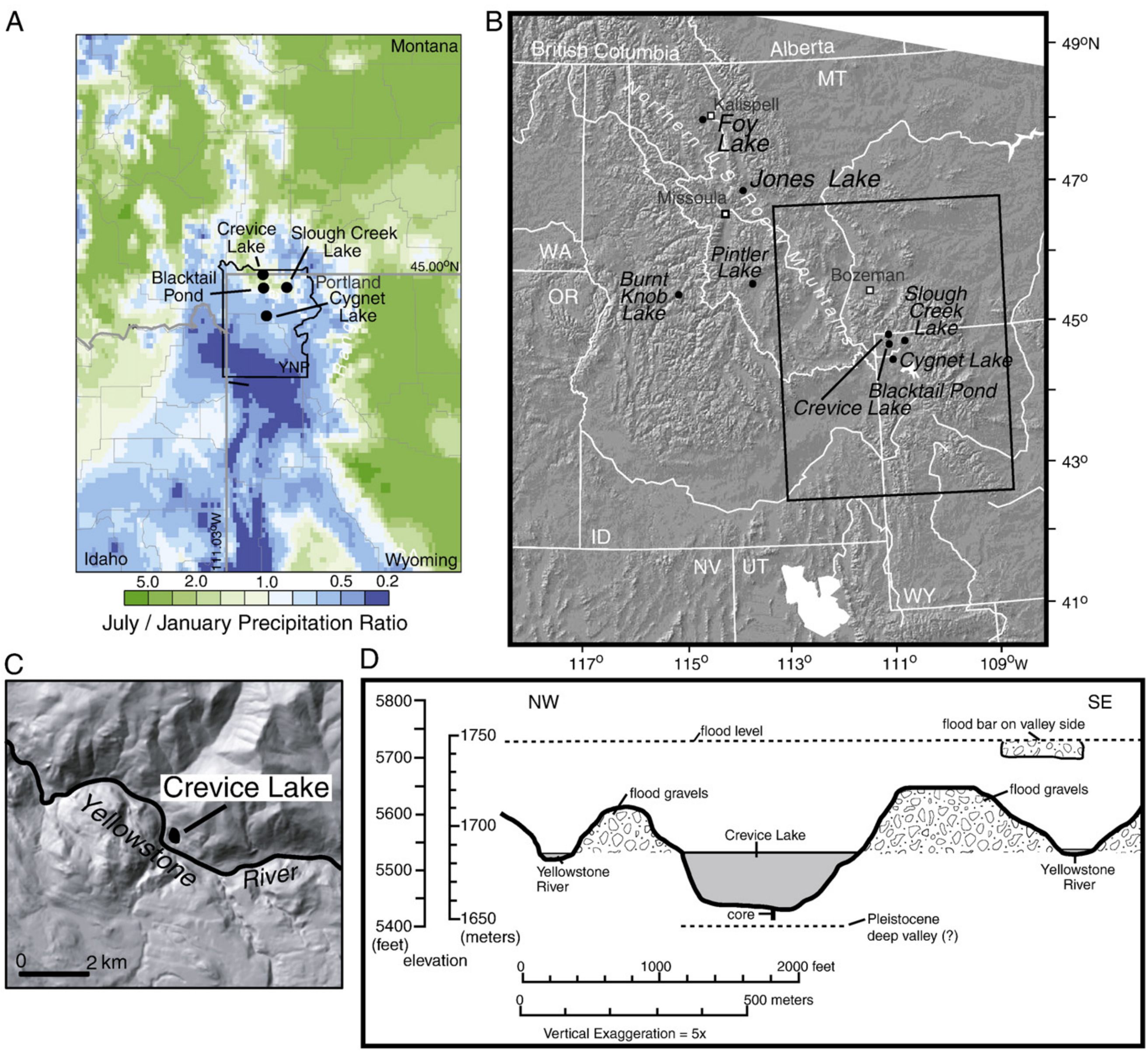


**Fig. 1.** Location of Crevice Lake. (A) Map showing present-day July/January precipitation ratios for 1971–2000 (PRISM Group, Oregon State University, http://www.prismclimate.org); (B) Location of sites discussed in the text; (c) Location of Crevice Lake in the Yellowstone River drainage; and (D) Cross section of the surface geology along a NW-SE transect through Crevice Lake.