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Deglacial and postglacial evolution of the Pingualuit Crater Lake basin, northern Québec (Canada)

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A B S T R A C T

The Pingualuit Crater, located in the Ungava Peninsula (northern Québec, Canada) is a 1.4-Ma-old impact crater hosting a ~245-m-deep lake. The lake has a great potential to preserve unique paleoclimatic and paleoecological sedimentary records of the last glacial/interglacial cycles in the terrestrial Canadian Arctic. In order to investigate the stratigraphy in the lake and the late Quaternary glacial history of the Pingualuit Crater, this study compiles data from three expeditions carried out in May 2007 (~9-m-long sediment core), in August 2010 (~50 km of seismic lines), and in September 2012 (high-resolution terrestrial LiDAR topography of the inner slopes). Despite the weak penetration (~10 m) of the 3.5-kHz subbottom profiling caused by the presence of boulders in the sedimentary column, seismic data coupled with the stratigraphy established from the sediment core enabled the identification of two glaciolacustrine units deposited during the final stages of the Laurentide Ice Sheet (LIS) retreat in the crater. Two episodes of postglacial mass wasting events were also identified on the slopes and in the deep basin of the crater. The high-resolution topography of the internal slopes of the crater generated from the LiDAR data permitted the confirmation of a paleolake level at 545 m and determination of the elevation of drainage outlets. Together with the mapping of glacial and deglacial landforms from air photographs, the LiDAR data allowed the development of a new deglaciation and drainage scenario for the Pingualuit Crater Lake and surrounding area. The model proposes three main phases of lake drainage, based on the activation of seven outlets following the retreat of the LIS front toward the southwest. Finally, as opposed to other high-latitude crater lake basins such as Lake El'gygytgyn or Laguna Potrok Aike where high-resolution paleoclimatic records were obtained owing to high sediment accumulation rates, the seismic data from the Pingualuit Crater Lake suggest extremely low sedimentation rates after the retreat of the LIS owing to the absence of tributaries.

1. Introduction

High-latitude lakes contain excellent archives of past climatic and environmental variations owing to the sediments they can preserve (Pienitz et al., 2004, 2008). In recent years, the Pingualuit Crater Lake (Nunavik; Fig. 1) has sparked a renewed interest in paleoclimatology research in the Ungava Peninsula (Black et al., 2010, 2012; Girard-Cloutier, 2011; Guyard et al., 2011, 2014; Luoto et al., 2013). Despite the presence of the Laurentide Ice Sheet during the Last Glacial Maximum (~21,000 years ago; Clark et al., 2009), the morphology of the crater likely favored the existence of a subglacial lake in the Pingualuit Crater, precluding glacial erosion of the bottom sediments (Bouchard, 1989b; Guyard et al., 2011). These characteristics give the Pingualuit Crater Lake sediments the potential to record successions of glacial/interglacial periods in the Ungava Peninsula since its formation 1.4 Ma ago (Bouchard, 1989b). Furthermore, the Pingualuit Crater Lake has similar characteristics to lakes recently studied in the context of International Continental scientific Drilling Program (ICDP) projects for their potential in paleoclimatic research, such as the El'gygytgyn Crater Lake in 2008/09 (e.g., Melles et al., 2012) and Laguna Potrok Aike in 2008 (e.g., Zolitschka et al., 2013, and papers in the special issue). El'gygytgyn Crater Lake, also a meteoritic impact basin located in the Arctic (67.5°N., 172°E.), escaped Northern Hemisphere glaciation because of its location in the center of Beringia (Brigham-Grette et al., 2007). Laguna Potrok Aike, located in southeastern Patagonia (Argentina), and the Pingualuit Crater Lake share a similar morphology with a high depth-to-area ratio, allowing the potential accumulation of a long sedimentary record

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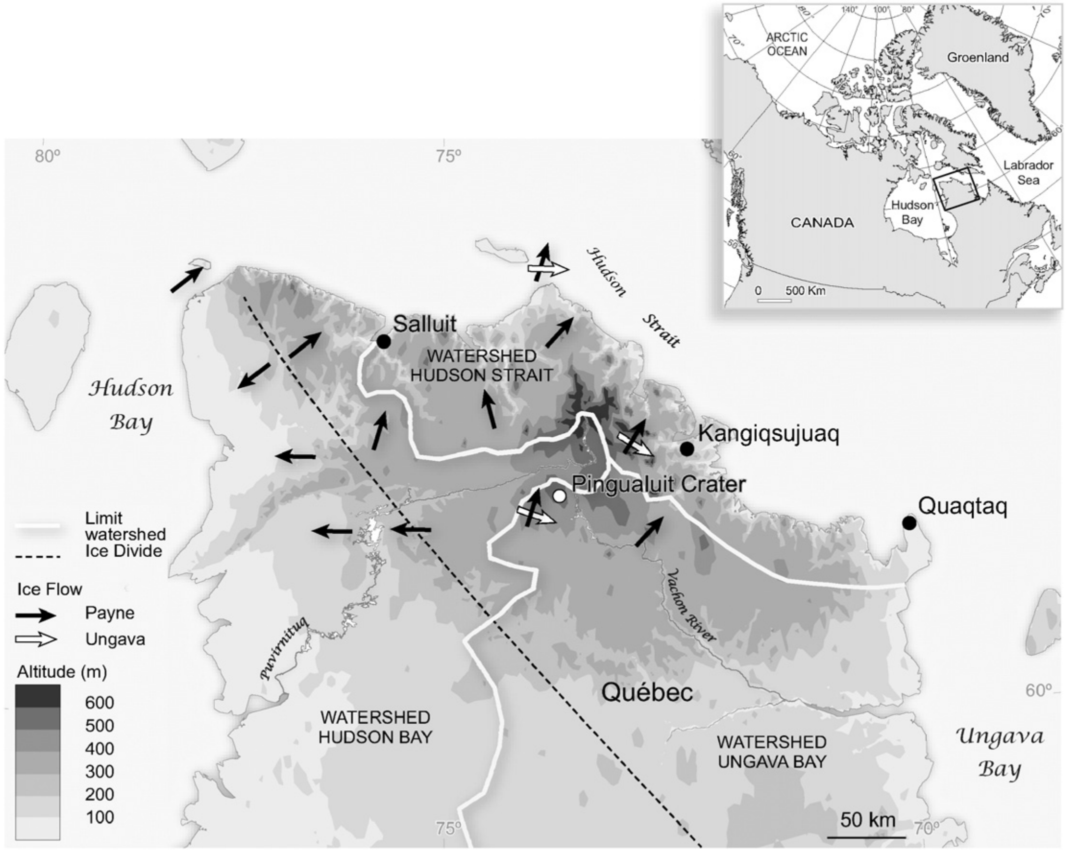

Fig. 1. Location of the Pingualuit Crater Lake in the Ungava Peninsula. Black and white arrows show the main ice flow directions (Payne and Ungava) based on depositional and erosional landforms (Bouchard and Marcotte, 1986; Daigneault and Bouchard, 2004). The dashed line illustrates the ice divide (Daigneault and Bouchard, 2004), and the white line marks the limit between the Ungava Bay, and Hudson Bay watersheds. Realization: Département de Géographie, Université Laval, 2013.

(Bouchard, 1989a; Anselmetti et al., 2009). The long sediment records obtained from such deep and old crater lake systems yield invaluable insights into the linkages between climate forcing mechanisms and global paleoenvironmental changes, thereby improving the output of regional and global climate models and contributing to a better understanding of past, present, and future climate change (Pienitz et al., 2008).

This study aims to investigate the late Quaternary glacial and deglacial history of the Pingualuit Crater Lake basin and to better understand the sedimentary infill of the lake based on recently acquired seismic and LiDAR data. These new and high resolution data sets, together with regional mapping of glacial and deglacial landforms based on aerial photographs, will contextualize and update the paleoclimatic archives recovered in the lake (Guyard et al., 2011, 2014; Black et al., 2012; Luoto et al., 2013), and allow reconstructing precisely the successive stages of crater deglaciation and the resulting rapid drainage events of the lake, first suggested by Bouchard and Saarnisto (1989). Indeed, the high-resolution topography of the inner crater, generated with the LiDAR data, confirms the presence of paleoshorelines visually tracked by Bouchard and Saarnisto (1989) and improves the resolution of elevation measurements from ± 5 to 1 m.

2. Study area

The Pingualuit Crater, located in the Ungava Peninsula (Nunavik, Canada; Fig. 1) is a simple crater created by a meteoritic impact ~1.4 million years ago (Grieve et al., 1991). The crater is a ~410-m-deep (rim-to-basin) and 3.4-km-wide (rim-to-rim) near circular depression whose rim reaches a maximum elevation of 657 m above sea level (asl), making it one of the highest peaks in Ungava. This summit rises to 163 m above the surface (494 m asl) of an ultraoligotrophic ~245-m-deep and 2.8-km-wide lake surrounded by the crater. Since the last deglaciation the lake has been a closed sedimentary basin with no tributaries as the lake is only fed by atmospheric precipitation (Guyard et al., 2011). However, $\delta^{18}O$ measurements made by Ouellet et al. (1989) in the Pingualuit Crater Lake and adjacent Lake Laflamme suggest a potential underground (cryptorheic) drainage system across a fault plane linking both lakes and allowing flows from the crater lake to Lake Laflamme (Currie, 1965). The water flows of the Pingualuit Crater area are drained by the Vachon River across the Ungava Bay catchment basin. The northernmost part of this area is adjacent to the Puvirnituq River, one of the main rivers of the Hudson Bay catchment basin (Fig. 1; Daigneault, 2008).

The crater is located in the Archean-age Superior Province of the Canadian Shield. The lithology in the area south of the Cape-Smith Belt, where the crater is situated, is dominated by tonalitic and granitic gneiss (St-Onge and Lucas, 1990; Daigneault, 2008). Around the crater, the bedrock geology also includes plutonic rocks, mostly granitoids, crosscut by mafic dykes (Currie, 1965; Bouchard and Marsan, 1989). The ground surface consists of blocks, gravels, and a 0–2 m-thick discontinuous till. Furthermore, dozens of erratic boulders of dolostone from the Proterozoic Cape-Smith Belt, located ~40 km north, have been counted in the crater area (Bouchard et al., 1989). The rim and steep inner slopes (26-35°) are also strewn with boulders and rocks mineralized with epidote, hematite, and sericite, probably produced by alteration (Currie, 1965). These slopes terminate on an asymmetric basin consisting of a plateau in the southwest part of the lake and a deep basin in the northeast part of the lake (Bouchard and Marsan, 1989). Bouchard (1989a) explains this morphology by high sediment input