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Tracking Holocene glacial and high-altitude alpine environments fluctuations from minerogenic and organic markers in proglacial lake sediments (Lake Blanc Huez, Western French Alps)

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A B S T R A C T

Holocene palaeoenvironmental evolution and glacial fluctuations at high-altitude in the western French Alps are reconstructed based on a multiproxy approach within Lake Blanc Huez (2550 m a.s.l.) drainage basin. The combination of seismic profiling (3.5 kHz), piston coring and radiocarbon dating in proglacial lacustrine sediments together with a detailed organic analysis of autochthonous and allochthonous supply allows documenting the evolution of glacier activity during the Holocene. Over the last 9700 years, the Holocene lake record has a bimodal pattern whose transition is progressive and occurring between 5400 and 4700 cal BP. During the Early Holocene, the organic lacustrine facies reflects reduced glacial activity in the catchment. This major glacial retreat seems to result from solar forcing and high summer insolation. After 5400 cal BP, lacustrine sedimentation is marked by the gradual increase both of minerogenic supply and soil erosion, suggesting a progressive transition to wetter climatic conditions. This climate change is synchronous both from the gradual decrease of summer insolation and the gradual reorganization of oceanic and atmospheric circulations, characterizing the beginning of the Neoglacial period. Both colder temperature and humid climate induced significant glacier advance, since 4700 cal BP. Over this global trend, three periods are particularly associated with higher runoff processes and higher soil erosion interpreted as wetter time intervals resulting from enhanced northern Westerlies regimes across the North Atlantic and Western Europe. They are dated from 8700 to 7000, 4700 to 2500 and 1200 to 200 cal BP. These wetter phases drastically contrast with periods of reduced glacial activities dated from the Early Bronze Age (ca 3870–3770 cal BP), the Iron Age (ca 2220–2150 cal BP), the Roman period (ca AD115–330) and the Medieval Warm Period (ca AD760–1160). In addition, these dryer periods are associated with mining activities at high-altitude.

1. Introduction

In order to better understand the potential effects of on-going climate change on continental environments, it is essential to disentangle the respective contributions of Holocene climate variability and the evolution of human activities on past environmental changes (Dearing and Jones, 2003; Magny, 2004; Desmet et al., 2005; Jungclaus et al., 2010). Glaciers are important climate indicators because their fluctuations are both sensitive to summer air temperature, winter precipitations and solar irradiance (Holzhauser et al., 2005; Vincent et al., 2005; Joerin et al., 2006). Over the past decades, Matthews and Karlén (1992), Leeman and Niessen (1994), Leonard (1997), Ariztegui et al. (1997) and Nesje

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et al. (2001) have demonstrated in various mountain ranges that proglacial lakes can provide continuous high-resolution sedimentary records of past glacial fluctuations in their catchments. Bedrock abrasion by a temperate glacier is maximal at the equilibrium line altitude (ELA) of the glacier (Dahl et al., 2003) and produces fine rock and mineral fragments ("glacigenic" or "minerogenic" material). During summer months, a relatively large amount of silt- and clay-size particles originating from glacial abrasion is transported in suspension by glacial melt waters and is deposited into proglacial lakes. Because erosion rate increases with glacier size and thickness, variations over time in the accumulated amount of glacigenic (or minerogenic) material in proglacial lake sediments provides a reliable high-resolution record of glacier activity and thus, of climate changes. Conversely, gyttja deposits in proglacial lacustrine environments are rich in organic matter (OM) but poor in minerogenic material and reflect periods without any significant glacier activity in the drainage basin (Nesje et al., 2001). Because OM in lakes can have different origins (either algal production, soil erosion or bedrock erosion) and since OM accumulation and preservation can reflect climatic regimes and global climatic conditions (Lallier-Vergès et al., 1993; Ariztegui et al., 1996; Sifeddine et al., 1996; Simonneau et al., 2013a). It is relevant to clearly quantify and qualify the different sources of OM accumulated in a proglacial lacustrine sequence.

Nowadays, high-altitude alpine environments (>2000 m) are essentially affected by the development of ski industry, the production of hydroelectricity and global warming (Anselmetti et al., 2007; Chapron et al., 2007; Guyard et al., 2007). Recent studies also revealed that the expansion of copper exploitation by the action of fire started during the Bronze Age period (beginning around 4350 cal BP in the southern French Alps and around 4200 cal BP in the Western French Alps). Such mining activities were concentrated in small areas and may have been exploited several times in ancient times (Bailly-Maître and Bruno-Dupraz, 1994; Guyard et al., 2007; Bailly-Maître and Gonon, 2006; Carozza et al., 2009; Garçon et al., 2012). Thus, in addition to former pastoral activities at lower elevation sites (Chardon, 1991), the past development of metallurgy above 2000 m altitude may have affected the altitude of the tree-line, paedological processes and/or runoff in this part of the Alps.

In the present paper, we document for the first time the evolution of glacier activity and soil erosion over the Holocene in a high-altitude (2500 m a.s.l.) proglacial lake from the western Alps (Fig. 1A) located on the windward side of the northern westerly wind belt originating from the Atlantic Ocean. Based on a

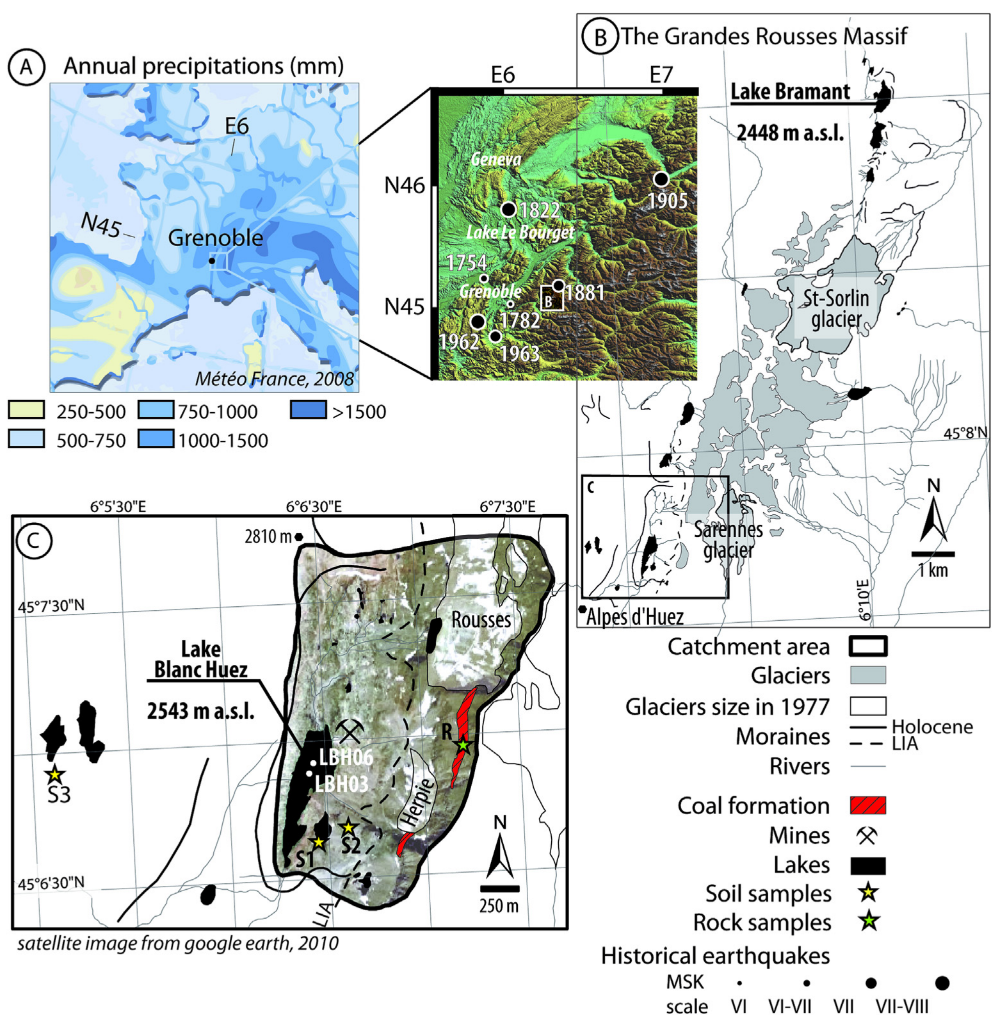

Fig. 1. Annual precipitation from Western Europe (A) and location of the Grandes Rousses massif in the active seismic zone of the western French Alps (B). Lake Blanc Huez is at the southern side of the Grandes Rousses massif (C). Its catchment area (thick black line, C) is partly covered by the Rousses and the Herpie glaciers. Their Little Ice Age (LIA, dashed line) and older Holocene moraines (thin black full line) are represented. As discussed in the text, the lake is also affected by human mining activities. The location of LBH06 piston core, three soil (S1, S2, S3, yellow stars) profiles and one rock sample from the Stephanian coal formation (R, green star) are also indicated in (C). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)