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Climatic significance of glacier retreat and rockglaciers re-assessed in the light of cosmogenic dating and weathering rind thickness in Clarée valley (Briançonnais, French Alps)

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ABSTRACT

Recent advances in geochronology provide opportunities to identify the glacial and periglacial sequences in mountain area. In this paper, we focus on the Upper Durance catchment (Southern French Alps), in the Clarée valley, where no absolute chronological benchmark was defined. Glacial remnants and periglacial features were investigated, integrated within a chronological scenario thanks to relative (weathering rind thickness) and absolute (CRE technique) dates. We find evidence of the existence of a Late-Glacial valley glacier, that has never been reported before. Then the upper valleys became ice-free during a period corresponding to the Early-Holocene Climate Optimum, whereas two sequences of cirque glaciation are identified during the second half of the Holocene. We also show evidence of three main generations of rockglaciers, which also mainly developed during the second half of the Holocene, probably at the end of the Subboreal period. The location and the altitudes of rockglaciers are strongly dependent on the geomorphic setting (especially the location of the sediment sources), hence complicating their palaeo-climatic interpretations.

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1. Introduction

Glacial and periglacial features are widespread in the mountains of European Alps; they may record climatic and environmental change that can be relevant to better understand the present climate trend and the Global Change issue. However, decoding such a record is still hampered by the scarcity of valuable ages of both glacial and periglacial landforms and by the complex interpretation of their palaeoenvironmental significance.

This problem can first be related to the paucity of organic matter in cold and dynamic alpine environments which prevent ^{14}C ages determination. Second, glacial sediments are rarely directly dated; this explains why most published articles refer to indirect approaches such as radiocarbon dating of adjacent, non-glacial deposits (e.g. peat deposits, lacustrine sequences, etc.) and requires discussions about the significance of the dated event. Third, the use of periglacial features for environmental reconstructions is complicated. Rockglaciers are probably one of the best periglacial geo-indicators for reconstructing climate variations (Barsch, 1978; Kerschner, 1983; Humlum, 1998; Frauenfelder et al., 2001) because their occurrence is generally associated to (discontinuous) permafrost conditions. Nevertheless, their climatic significance is not evident to decipher because of the complexity of their genesis and their growth that also generally necessitate favourable conditions for large supply of coarse debris (Berthling et al., 1998; Humlum, 2000; Fort, 2003; Berthling and Etzelmüller, 2007).

Fortunately, the development of dating techniques (such as Cosmic Ray Exposure dating—CRE) that can be applied to non-organic deposits offers exciting perspectives for the dating of geomorphic features in high alpine areas. However, acquisition and interpretation of absolute dates require the definition of a relative scenario of past sequences, based on distinctive landforms distribution, and degree of weathering of associated sediments (*i.e.* soil development or weathering rind thickness). Collectively, relative chronologies and CRE techniques may help completing the glacial history and may provide some chronological benchmarks on some rockglaciers. Finally, the circumstances of rockglacier genesis and growth can be discussed and their climatic significance better understood.

A focus on the Upper Durance Catchment (Briançonnais Alps) (Fig. 1) would help us to progress toward such objectives. The

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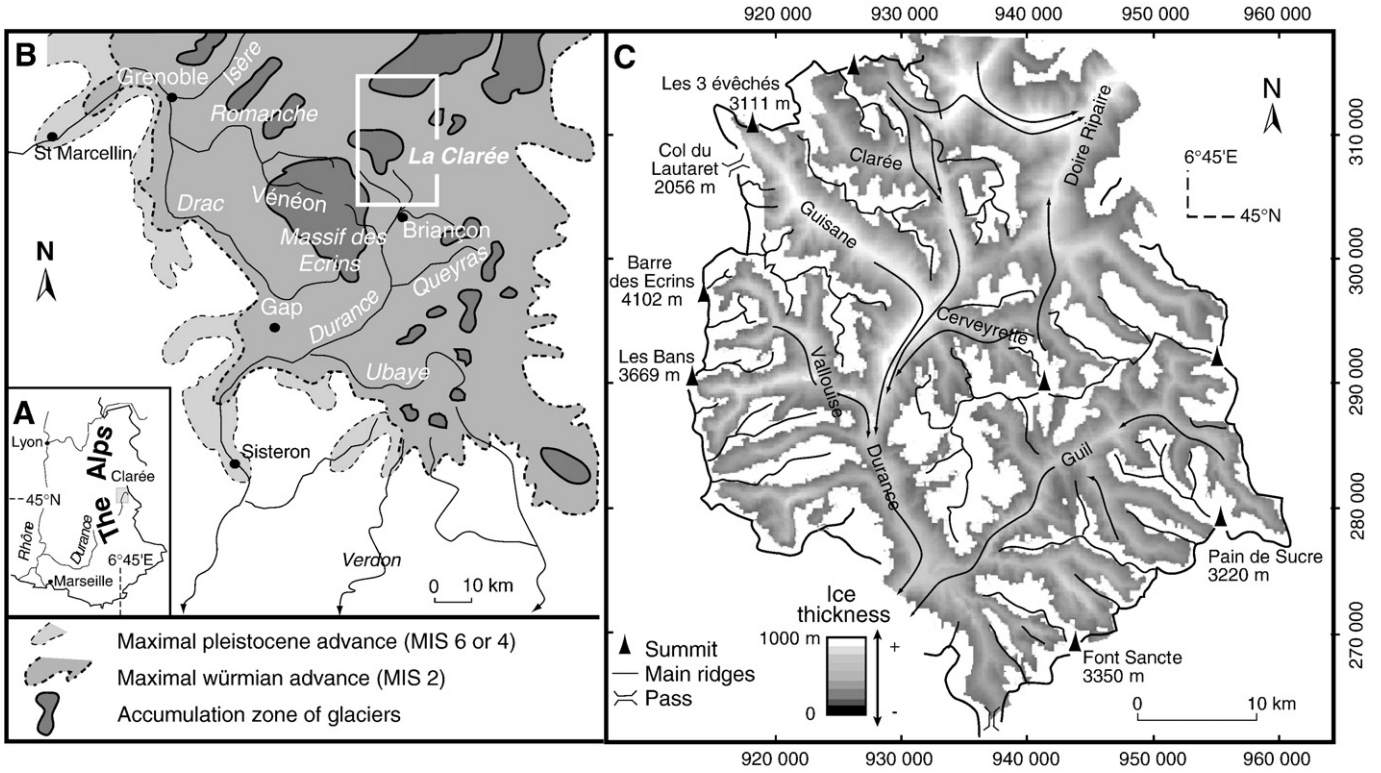

Fig. 1. Location of the study area. A: General location in the south-eastern France. B: The Upper Durance catchment within the Southern French Alps, during the Last Glacial Maximum (after Montjuvent and Nicoud, 1988, modified). C: Reconstruction of glacier thickness during the Last Glacial Maximum. Geographical coordinates are in meters, Lambert II étendu (after Cossart, 2008, modified).

palaeoenvironmental history is mostly unknown in the Briançonnais Alps. In this paper, we make an inventory of glacial remnants and investigate thirty-one rockglaciers to reconstruct former environments, since the Last Glacial Maximum. CRE method is here coupled with the assessment of weathering rind thickness, to provide absolute chronological benchmarks and to constrain in time the glacial and periglacial sequences recognized in the field. Finally we propose a first scenario of the palaeoenvironmental evolution of this area, and discuss the conditions in which rockglaciers developed.

2. Remaining questions about the environmental history

The Durance is the main trunk valley of the Southern French Alps, and it was occupied by one of the largest glaciers in the Alps during the Last Glacial Maximum (Fig. 1B). As in other parts of Europe, the maximal extent of glaciers is assumed to have occurred during the Rissian stage (Marine Isotopic Stage—MIS-6) within the Southern French Alps (Montjuvent and Nicoud, 1988; Ehlers, 1996; Hughes et al., 2006). However, other set of data suggests that the glacial maximum may have been younger, around 60–75 ka ^{10}Be BP, during the MIS 4 (Brocard, 2003). Unfortunately, glacial remnants documenting such remote periods are scarce and rare because of later intense reworking in these geomorphically dynamic environments (Jorda, 1988).

Whereas the identification of Würmian and post-Würmian relicts is more obvious in the field, absolute chronologies remain rare. Two absolute scenarios of glacial sequences have been proposed, one in the western part of Massif des Écrins (Edouard, 1979) and the other one in the Ubaye and Verdon valleys, close to the Maritime Alps (Jorda, 1988, 1993; Jorda et al., 2000). According to both sequences, the Last Glacial Maximum occurred around 24 ka BP and the last Würmian advance took place between 22 and 20 ka BP (MIS 2). However, the post-Würmian sequences were probably quite different in these two areas. On the one hand, in the western part of Massif des Ecrins, two main stages of glacier recession are identified. The first one occurred after the LGM and before the Oldest Dryas. Despite this, large valley glaciers were still present during the Late-Glacial period, with their fronts descending close to 1000 masl, and their thickness was about several hundreds of meters. A second stage of glacial shrinking occurred at the beginning of the Holocene, and was characterized by the final disappearance of the major glacial tongues. In the Ubaye and Verdon valleys on the other hand, the deglaciation was rapid, characterized by one main stage only. The valley glaciers disappeared between 18 and 15 ka whereas small cirque glaciers lasted during the Late-Glacial period. A few small glaciers were still present around the highest summits of the area during the Holocene; they were affected by minor fluctuations.

Estimations of rockglaciers ages are even more difficult. Southward, in Ubaye and Verdon valleys, most of inactive rockglaciers were interpreted as Late-Glacial features (Jorda, 1983; Evin, 1987); they were assumed to develop during a cold and dry period such as the Younger Dryas. Other studies in Massif des Écrins and in Massif de la Vanoise are in agreement with this interpretation, even if they point out that some very large rockglaciers would develop in a shorter time than previously expected, implying a younger age than forecasted (Francou, 1988; Monnier, 2006).

Finally, little is known about glacial and periglacial past sequences in a large part of the Southern French Alps, especially in the Upper Durance catchment (Briançonnais Alps). In this area, some pioneers provided initial descriptions of glacial and periglacial landforms (Touchon, 1910; Allix, 1924; Peguy, 1947), but the chronology of the sequences described still remains poorly documented. Some detailed geomorphic maps were published, providing local inventories of the glacial and periglacial landforms (Francou, 1988; Barfety et al., 1995; Lahousse, 1994; Colas, 2000), but the chronological sequences were deduced from the radiometric ^{14}C dates acquired westward or southward. Only a single ^{14}C date on travertine limestones has been obtained in the Briançonnais Alps, in the Guisane valley (Chardon,

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