Earth and Planetary Science Letters 293 (2010) 72–83

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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

Frost-cracking control on catchment denudation rates: Insights from *in situ* produced ^{10}Be concentrations in stream sediments (Ecrins–Pelvoux massif, French Western Alps)

Romain Delunel [a,*], Peter A. van der Beek [a], Julien Carcaillet [a], Didier L. Bourlès [b], Pierre G. Valla [a]

[a] *Laboratoire de Géodynamique des Chaînes Alpines, Université Joseph Fourier, BP 53, 38041 Grenoble, France*

[b] *Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement (CEREGE), UMR 6635 CNRS-Aix Marseille Université, BP80, 13545 Aix en Provence, France*

A R T I C L E I N F O

Article history:
Received 14 September 2009
Received in revised form 11 February 2010
Accepted 12 February 2010

Editor: R.W. Carlson

Keywords:
European Alps
10Be
catchment denudation rates
frost cracking

A B S T R A C T

The potential tectonic and climatic controls on erosion rates in the European Alps and other mountain belts remain strongly debated. We have quantified denudation rates at catchment scales using *in situ* produced cosmogenic nuclides (^{10}Be) in stream sediments, sampled at the outlets of twelve variously sized (27–1072 km^2) catchments of the Ecrins–Pelvoux massif (French Western Alps), with average elevations ranging from 1700 to 2800 m. Spatially-averaged denudation rates, corrected for potential shielding by Little Ice Age glaciers, vary from 0.27 ± 0.05 to 1.07 ± 0.20 mm/yr on millennial timescales. Our results exhibit a correlation ($\rho^2 = 0.56$) between denudation rate and mean catchment elevation, in the absence of significant correlation with any other morphometric parameters (relief, slope, catchment size, hypsometry, etc). Although such variations in erosion rates have been previously linked to variations in tectonic uplift rate, the relatively small size and tectonic homogeneity of our study area exclude a strongly variable tectonic control. We interpret the increase in erosion rate with elevation as the effect of frost-controlled processes, which are strongly temperature-dependent. We use a one-dimensional heat-flow model driven by high-resolution instrumental temperature records from the study area to correlate the variability in denudation rates with the integral of the absolute temperature gradient within the frost-cracking window (-3 to -8 °C), a proxy of the frost-cracking intensity, for each catchment. The results imply that the efficiency of frost cracking constitutes a major control on catchment-wide denudation rates in the study area, explaining more than half the measured variability in these rates. Our study shows that present-day denudation of the Ecrins–Pelvoux massif is controlled by a climatically driven factor and suggests that frost-cracking processes impose an important control on the post-glacial topographic evolution of mid-latitude mountain belts.

1. Introduction

The relative roles of tectonics and climate in shaping mountainous topography remain controversial and relatively unconstrained. In particular, several authors have suggested that glacial processes play a major role in setting denudation rates and limiting elevations in mountain belts worldwide (e.g., Brozovic et al., 1997; Mitchell and Montgomery, 2006; Egholm et al., 2009). Concomitantly, the interplay between Quaternary climate change and relief development (e.g., Molnar and England, 1990; Small and Anderson, 1995) remains not well understood. Quantification of the spatial and temporal variations in denudation rates provides a key to address these questions. Comparing the spatial variations of denudation rates and topographic metrics allows to further constrain the controls on denudation (e.g., Summerfield and Hulton, 1994; Montgomery and Brandon, 2002).

The European Alps provide an ideal case to study potential climatic impacts on relief development, as current tectonic deformation rates are minimal, at least in the western part of the orogen (Calais et al., 2002), but it has been extensively glaciated during Quaternary times. As a result, the transient relief of the Alps appears to have significantly increased recently and bears a strong glacial imprint (Schlunegger and Hinderer, 2003; Champagnac et al., 2007; van der Beek and Bourbon, 2008). Alpine denudation rates have been quantified on different space- and timescales from lake- and valley fills (Hinderer, 2001), *in situ* and detrital cosmogenic isotope data (Wittmann et al., 2007; Norton et al., in press) and low-temperature thermochronology (Vernon et al., 2008 and references therein). These rates have been shown to correlate spatially with both elevation and present-day rock uplift (Schlunegger and Hinderer, 2001; Wittmann et al., 2007; Vernon et al., 2009), suggesting they are coupled (Champagnac et al., 2007; 2009). However, although isostatic rebound provides the

* Corresponding author. Tel.: +33 476 63 54 64; fax: +33 476 51 40 58.
E-mail address: romain.delunel@e.ujf-grenoble.fr (R. Delunel).

0012-821X/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsl.2010.02.020

coupling between erosion and rock uplift, it is not obvious how the feedback between uplift, elevation and erosion would occur in the absence of strong tectonic forcing.

Here we report cosmogenic ^{10}Be denudation rates measured for 12 catchments of the Ecrins–Pelvoux massif, French Western Alps. Combining denudation rates with topographic metrics obtained from Digital Elevation Model analysis, we show that catchment denudation rates are correlated with mean catchment elevation, in the absence of correlations with any other topographic metric. Inferred denudation rates in our spatially restricted and tectonically uniform study area vary over an almost similar range to those reported by Wittmann et al. (2007) across the entire central Alps. Using well-calibrated relationships between mean annual temperature, the amplitude of its variation, and elevation, together with a recent numerical model for frost-cracking intensity (Hales and Roering, 2007), we show that denudation of the Ecrins–Pelvoux massif is climatically controlled by frost-shattering processes on post-glacial timescales, as has recently been proposed for other mountain

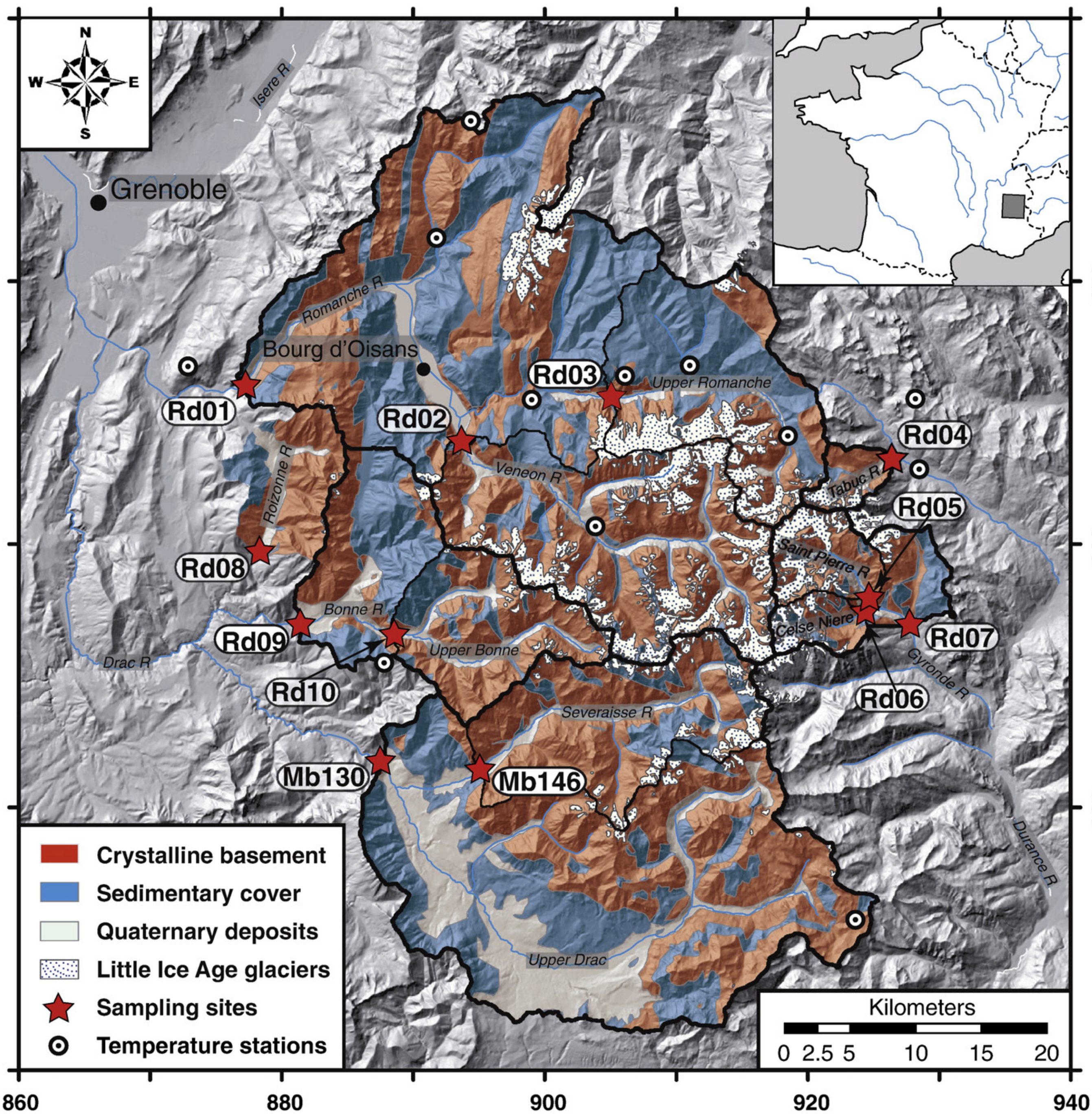

Fig. 1. Geomorphic setting of the study area, showing sample locations: shaded Digital Elevation Model based on *Institut Géographique National* 50-m resolution digital topography data. Eastings and northings are according to IGN Lambert-III grid in kilometres; inset shows location within France. Red stars indicate sample locations and correspond to outlets of upstream catchments (solid black lines). Areas that contribute to the quartz fraction of sampled stream sediments correspond to crystalline basement (red surface) and quartz-bearing Quaternary deposits (light grey surface). Non-contributing areas corresponding to Mesozoic marly–calcareous sedimentary cover are represented in blue. Catchment lithology from 1:100,000 scale digital geologic map produced by the *Parc National des Ecrins*. Blue dotted white areas represent Little Ice Age glacial extent (Edouard, 1978). Dotted black circles represent locations of temperature stations.