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Deglaciation chronology of the Ecrins-Pelvoux massif (French Western Alps) revealed from new ^{10}Be and ^{26}Al Cosmic Ray Exposure ages.

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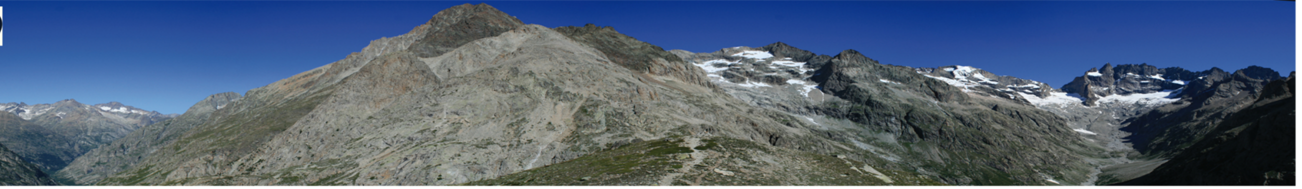
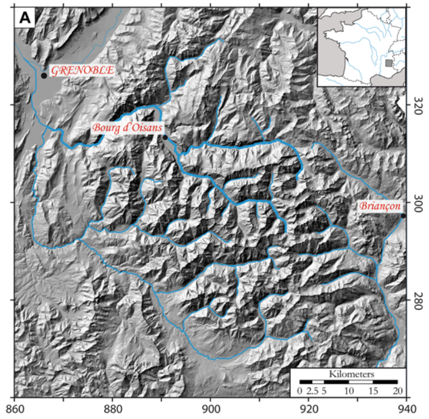
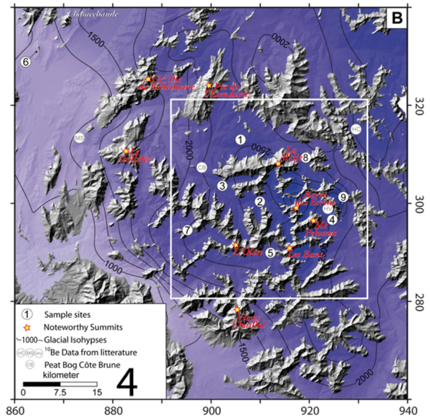


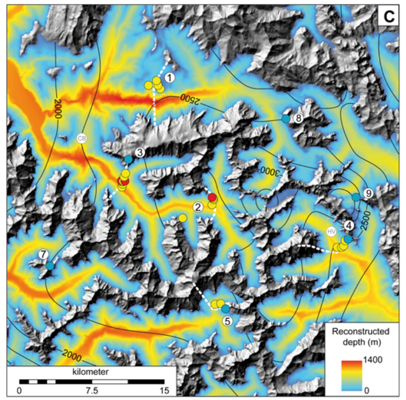
We report new cosmic ray exposure (CRE) ages (^{10}Be and ^{26}Al) obtained within the Ecrins-Pelvoux massif (French Western Alps), which contribute to improve the late Pleistocene and Holocene deglaciation chronology at the massif scale.

- We sampled various Quaternary morphologies showing glacial features, focussing on 4 vertical profiles
- Double cosmogenic isotope measurements theoretically allow the identification of complex surface exposure histories (i.e. rejuvenation of the cosmogenic signal by glacier erosion).

1/ GEOMORPHIC SETTING





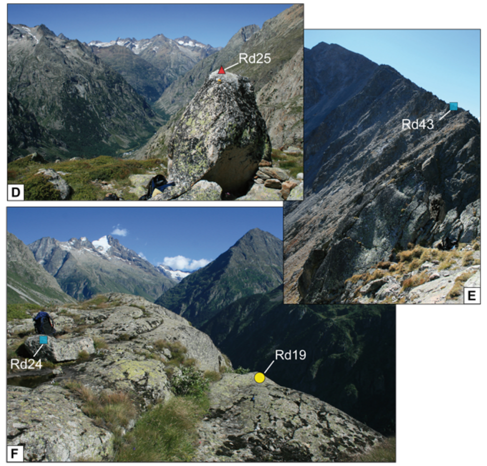


(A) Present day topography from *Institut Géographique National* Digital Elevation Model (50-m resolution). Eastings and northings are according to IGN Lambert-III grid (in km).

(B) Glacial paleogeographic reconstruction during the Quaternary Glacial Maximum Extension (extrapolated from published works[1, 2, 3]. Reconstruction is based on spatial extrapolation of observed glacial morphologies. The blue intensity represent the maximum elevation of the ice cap.

(C) Zoom of the study area (White frame on B). The glacier thickness is the deduced from the difference between ice surface and topographic elevation computed from the DEM. Dots localize the samples, colors refer to the type of sampled glacial features (i.e. yellow: roches moutonnées, red: erratic boulders; blue: nunataks). White dashed lines localize the topographic transcets chosen for sampling.

Sample sites



Erratics.

(D) View of the Vénéon valley from the *Tête de la Maye* (site 2). Sampled granite erratic is approx. 2.5 m high.

Nunataks.

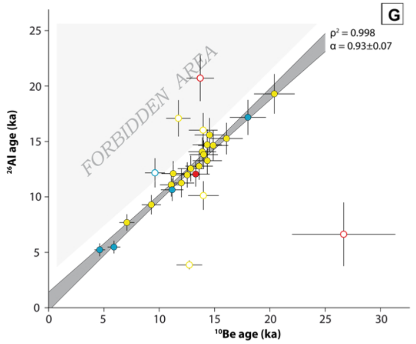
(E) View of the crest connecting the *Col de Laurichard* (foreground) and the *Roc Noir de Combeynot* (background) (site 8). The granite is extensively fractured and the crest produces large amounts of detrital material.

Roches moutonnées.

(F) View of two samples of the *St Christophe en Oisans* vertical profile (site 3), within the Vénéon valley. Sampled roche moutonnée (Rd19) is in basement gneiss. The erratic is in granite.

2/ RESULTS

^{10}Be and ^{26}Al concentrations have been measured in 32 and 28 samples, respectively. CRE ages range from 5.9±0.6 to 26.7±4.6 ^{10}Be-ka and from 3.9±0.4 to 20.7±2.1 ^{26}Al-ka.
Ages computed from different morphologies (i.e. roches moutonnées, erratic boulders and nunataks) are consistent for the 2 elements but both evidence large variability (>10 ka).
Only one sample (Rd23, erratic block) show a significant variability between ages computed from ^{10}Be (26.7±4.6 ^{10}Be-ka) and ^{26}Al (6.6±2.9 ^{26}Al-ka).



(G) **^{10}Be and ^{26}Al CRE ages** (yellow: roches moutonnées, red: erratic boulders; blue: nunataks).

- Full circles represent samples (20) that show a 1:1 linear relation for both ages. The shaded area shows the analytical uncertainty in the ^{10}Be-^{26}Al age relationship for these samples.
- Open circles represent samples that significantly deviate from the theoretical 1:1 line.

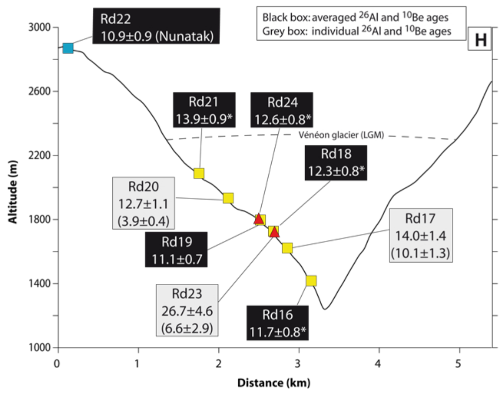
Most samples (75%) suggest a simple scenario of uninterrupted exposure to cosmic rays: no geological disturbance on both ^{10}Be and ^{26}Al production

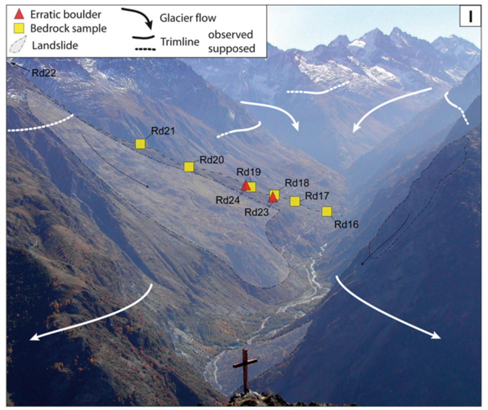
25% (7 samples) suggest a complex exposure scenario.
- 4 of these are aberrant because they are located in the "forbidden area" (^{26}Al/^{10}Be > 6.75);
- 3 are located below the 1:1 line but require a burial time >700 ka, which is incompatible with the geomorphological context.

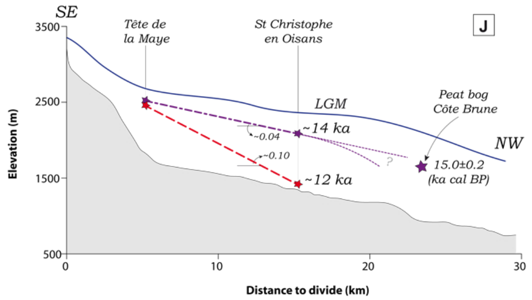
Considering this, the glacial chronology has been reconstructed with only internally consistent ^{26}Al and ^{10}Be data (filled symbols).

3/ GLACIAL CHRONOLOGY IN AN INNER VALLEY - VENEON

Saint Christophe en Oisans elevation transect ⟶ chronology of deglaciation







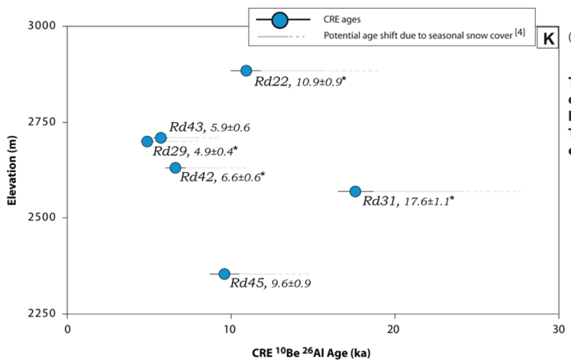
Gradual lowering of the Vénéon glacier surface between ~14 ka and ~12 ka. (Figures H and I)

CRE dating and sample locations allow the establishment of glacier surface evolution.

The Late glacial evolution of the Vénéon glacier surface is diachronic (Fig J). The dashed lines show linear interpolations of sample elevations of similar ages at Saint Christophe and the upstream Tête de la Maye site (14 ka and 12 ka). The average glacier slope ranged from 4% (14 ka) to10% (12 ka).

The reconstructed surface evolution shows that retreat of the glacier front is associated with surface steepening. This feature is related to the varying distance to the accumulation zone and explains locally variable deglaciation histories.

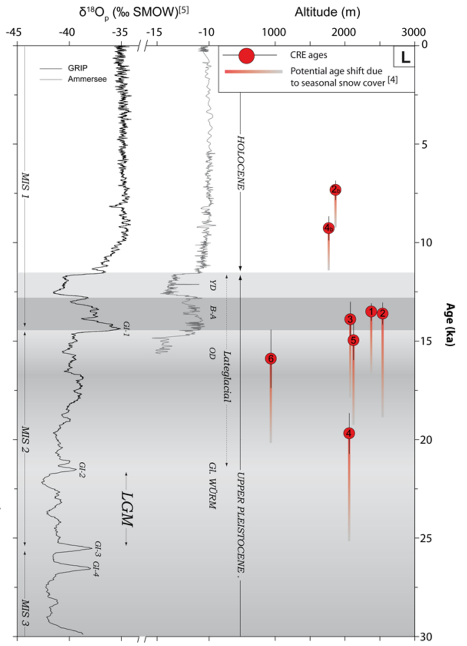
4/ FROST-SHATTERING EFFECT ON NUNATAK AGES?



(K) Spatial distrubution of CRE ages of Nunataks

The wide and young age-range (~5 to ~11 ka) encountered on nunataks is incompatible with long term exposure of non-glaciated surfaces. This suggests significant effects of frost-shattering on the morphological evolution of the nunataks.

5/ REGIONAL SYNTHESIS OF GLACIAL CHRONOLOGY



(L) **Global climatic context and initiation of glacial retreat in the Ecrins-Pelvoux massif.**
Numbering refers to the sites in Figure B.
Marine Isotope Stages (MIS), Last Glacial Maximum (LGM) and Greenland interstages (GI) are from Svensson et al. [6] B-A: Bølling-Allerød; YD: Younger Dryas.

The initiation of deglaciation occurs just after the end of the LGM during millennial-scale global temperature increases (GI-2 and Bølling-Allerød).

A contrasted East/West forcing is suggested by early lowering of the Vallouise Glacier (site 4 on Figure L), located on the eastern flank of the massif. The western front shows longer resilience of the glacial systems (Isère/Romanche, site 6; Drac, site 5; and Romanche/Vénéon, sites 1, 2, 3).

Glaciers located in the highest valleys (Romanche and Vénéon) reveal a lag between the climatic pulse and the response of the glacier.

The Vénéon, Romanche and Séveraisse Valleys (site 2, 3 and 5 respectively) **conserved surface altitudes similar to those of the LGM until the Bølling-Allerød.** This is compatible with observations from the Saas valley, Switzerland[7]

The end of the main episode of deglaciation coincides with the Younger Dryas (cold period)/pre-Boreal (warmer period) transition. Since the beginning of the Holocene, glaciers are limited to the upper-most zones of valleys.

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