# Relief and paleoenvironmental conditions during the mid-late Miocene in the French Western Alps (Dévoluy Massif) revealed by Obiou cave deposits

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## Abstract

*Cave levels at high elevations (2250-2370 m), hosting allochthonous sediments with clear provenance from the Pelvoux External Crystalline Massif were identified in the Obiou mountain, Dévoluy Massif (French Western Alps). These deposits result from burial of alluvial sediments of the paleo-Drac River in Miocene times (burial ages of ca. 10-15 Ma). The Drac River is currently situated 1600 m below the caves, indicating significant post-middle Miocene fluvial incision. The pollen analysis on clay cave infill indicates a humid and warm climate, typical for Western Europe in the mid-late Miocene. It also reveals the presence of dinoflagellate cysts from coastal and lagoon environments suggesting deposition of the clays in the caves when they were close to sea level. These findings indicate uplift of the caves of at least 2000 m since the mid-late Miocene. Furthermore, the pollen assemblage originated from different vegetation belts, in agreement with existing data for mid-late Miocene deposits in the western Alps. The pollen flora includes cool-temperate and boreal trees, suggesting high-elevated source areas for the deposits within the Pelvoux catchment. These data confirm the exceptional character of the Obiou cave deposits that provide new geomorphologic constraints for the evolution of the French Western Alps.*

## 1. Introduction

Cave deposits are a valuable tool to reconstruct past relief and environmental changes, especially in regions where sediments on the surface are not preserved, as is often the case in mountainous areas characterized by efficient erosion. Furthermore, the development of horizontal caves may be linked to paleo-river levels, analogous to alluvial terraces as soon as infill deposits are trapped in karstic systems. The difference with the modern river elevation can be interpreted in terms of fluvial incision, and ultimately in terms of surface uplift when paleo-elevations of caves can be quantified. However, inferring paleo-elevation of caves is generally difficult. One of the means to define a paleo-elevation is to study the pollen assemblages from sediments, as the type of vegetation depends on the mean annual temperature (MAT), which in turn depends on latitude and altitude. The analysis of pollen flora from Paleogene and Neogene foreland-basin sediments provides insights on the evolution of Alpine topography (FAUQUETTE *et al.*, 2015), but such data remains scarce. We employed this method on clay deposits from a high-elevation cave with datable allochthonous infill found in the Obiou (Dévoluy Massif), in order to estimate paleo-elevation and paleoenvironmental conditions during their deposition. These results helped assessing the long-term uplift of the Dévoluy Massif.

## 2. Geological setting and descriptions of the studied caves

The Dévoluy Massif is situated to the west of the Ecrins (Fig. 1), which is part of the Pelvoux External Crystalline Massif (ECM). The Dévoluy is a subalpine karstic massif consisting of Upper Cretaceous limestones folded in a N-S synclinorium, containing Paleogene foreland-basin sediments (Eocene and Oligocene molasses originated from the Internal Alps). The Dévoluy area comprises some of the oldest caves identified in the French Alps (JAGERCIKOVA *et*

*al*., 2021). Allochthonous deposits were recognized in three caves (Baume des Jalabres, Baume du Petit Odieux, Baume du Calvaire) in the Obiou (2789 m), located at an altitude ranging from 2250 to 2370 m asl. Cave deposits include rounded crystalline pebbles (pseudo-spheres and rods), sands and clays, present in some cases as consolidated conglomerates. JAGERCIKOVA *et al.* (2021) determined $^{26}Al/^{10}Be$ and $^{10}Be/^{21}Ne$ burial ages of Jalabres Cave deposits to 15.6 ± 3.8 Ma, which was refined to 10 ± 2 Ma, respectively (by LEMOT (2021). Both burial ages relate the deposition of such conglomerates to mid-Miocene ages. These infills were interpreted as alluvial, originating from the southern Ecrins (Pelvoux ECM). Indeed, the petrographical analysis of the infill showed mostly granites, various metamorphic rocks, sandstones and volcanic clasts (JAGERCIKOVA *et al*., 2021). The Jalabres Cave preserved magnificent meandrous morphologies (5-m wide, 30-m high), which indicate an important underground flow. The drainage would correspond to the paleo-Drac River, that has a modern level situated ~1600 m below the studied caves (Fig. 1). The recognition of these cave deposits is important for several reasons: 1) it shows that the Pelvoux basement was already exhumed and actively eroded since the mid-Miocene; 2) the summit of the Obiou is located currently 400 m above the investigated caves implying that the Dévoluy Massif already had an uplifted landscape during the mid-Miocene with the development of old karst settings; 3) an important fluvial incision of the Drac River (at ~1600 m), related to the surface uplift has occurred since the mid-Miocene. The amount of fluvial incision can be therefore roughly estimated from the elevation difference between the cave levels and the modern river. However, the quantification of surface uplift requires additional information about the paleo-elevation of caves at the time the allochthonous infill was deposited inside the karst systems.


*Figure 1: Photograph showing the Obiou and cave level at 2300 m with allochthonous deposits.*

# 3. Methods

In order to better understand the paleoenvironmental conditions during the infill deposition, we performed a palynological analysis on clay deposits from the Petit Odieux Cave (2250 m asl), a horizontal cave almost completely filled with various types of infill. The allochthonous deposits of this cave consist of broken polygenic conglomerates, including crystalline pebbles, limestone blocks, sands and mud clasts, and mica-rich clay infills. Many conglomerates and clays were likely post-depositionally perturbed as they are not in stratigraphic position. However, some clay deposits are located in protected spaces inside the cave and show layered structures. This layered clay was sampled for palynological analysis. First, sample of 60-70 g was processed using the classic method to extract palynomorphs (acid attacks with HCl and HF, heavy liquid $ZnCl_2$) and then sieved at 10 µm. Second, the identification of palynomorphs in the sample was conducted using a microscope at x1000 magnification. Fluorescence light was used in parallel to exclude recent contamination or reworking of palynomorphs. Pollen grains were identified at the genus or family level and classified according to their ecological signification following NIX (1982). The entire residue from the chemical processing was analyzed and provided a total of 102 pollen grains, a number which is relatively low, but significative enough of the vegetation belts with respect to our database of modern pollen floras and their relationship to vegetation in the region. The pollen flora allows the reconstruction of the mean annual temperature (MAT) during the deposition of the cave deposits. This *Climatic Amplitude Method* compares the present-day pollen records distributed worldwide with the identified pollen species in the studied cave deposits. It relies specifically on the relationship between the relative abundance of each individual taxon and climate. The MAT value, together with pollen flora and the vertical shift in the vegetation belts in relation to latitude, is used to quantify the paleo-elevation of a massif (see details of the methods in FAUQUETTE *et al*., 2015).

# 4. Results

The clay sample from the Petit Odieux Cave is relatively poor in palynomorphs (see Table 1). The analyzed sample contains 102 pollen grains, 34 spores of Pteridophytes, 206 spores of Bryophytes and 2 dinoflagellate cysts that could be identified. Most of the palynomorphs are well-preserved and they show significant diversity in the vegetation types, with different paleo-ecological significations. The presence of mega-mesothermal plants, with estimated mean annual temperature of ca. 15.4 °C (range: 10–20 °C), indicates warm conditions. Tree pollen of swamp and riparian forests are quite frequent (*Taxodium*-type, *Alnus*, *Carya*, *Liquidambar*, *Zelkova*). The presence of *Osmunda* is consistent with a swampy environment and the abundance of *Pteridophyte* spores, lacking perispores, suggests important runoff conditions. Then, pollen grains of mid-altitude subtropical trees (*Cathaya*, *Sciadopytis*), warm-temperate trees (mostly *Quercus* and *Zelkova*), cool-temperate trees (*Fagus*, *Tsuga*) and boreal trees inhabiting high altitude (*Picea*) were recognized. The presence of such taxa suggests the existence of different vegetation belts in the catchment area (Ecrins sector, Pelvoux ECM). The palynological analysis also revealed the presence of 2 dinoflagellate cysts, *Lingulodinium machaerophorum* and *Pentapharsodinium dalei*; these are coastal to lagoonal species indicating depositional settings close to sea level. The presence of Amaranthaceae and other herbaceous plants is related to coastal environment settings. There is no difference between pollen grains and dinoflagellate cysts under fluorescence light. Therefore, the cysts were not reworked from older deposits and are contemporaneous with the other palynomorphs. Considering the burial age interval (ca. 10-15 Ma), this pollen flora is probably younger than the Mid-Miocene Climatic Optimum (MMCO: 17–14 Ma), because it does not include megathermal (i.e., tropical plants). We thus consider the deposits younger than 14 Ma (mid-late Miocene in age). At that time, the ratio between the altitudinal and latitudinal temperature gradients was supposed to be similar to the present ratio. This implies a relationship in which vegetation belts shift 110 m / one degree of latitude. The reconstructed MAT of 15.4 °C is found today at ~42 °N (i.e., ~2.8° further south of the Obiou). Vegetation belts were therefore shifted ~300 m higher in altitude to compensate higher temperature environments than the present-day. Nowadays, the spruce (*Picea*) forest develops in the Ecrins from ~1600 m altitude. Based on the MAT reconstruction relationship, this same forest must have developed above ~1900 m during the mid-late Miocene. The estimated basal altitude of the spruce forest ~300 m above its present altitude gives an analogical minimum altitude estimate for the mid-late Miocene Pelvoux Massif. In the case the spruce altitudinal belt was complete (as suggested by the significant pollen percentage), the maximum altitude of this forest would then reach ~2600 m, assuming that the amplitude of a vegetation belt is ~700 m).

| | |
|---|---|
| **Subtropical (mega-mesothermal) plants:** | |
| *Engelhardia* | 3 |
| *Sequoia*-type | 8 |
| *Taxodium*-type | 2 |
| **Mid-altitude subtropical trees:** | |
| *Cathaya* | 16 |
| *Sciadopitys* | 2 |
| **Warm-temperate (mesothermal) trees:** | |
| *Alnus* | 2 |
| *Carya* | 2 |
| *Liquidambar* | 1 |
| *Quercus* | 7 |
| *Zelkova* | 3 |
| **Cool-temperate (meso-microthermal) trees:** | |
| *Fagus* | 3 |
| *Cedrus* | 1 |
| *Tsuga* | 1 |
| **Boreal (microthermal) trees:** | |
| *Picea* | 11 |
| **Trees without signification (cosmopolitan trees):** | |
| *Pinus* | 19 |
| Pinaceae altered pollen grains | 9 |
| *Cupressus-Juniperus*-type | 1 |
| **Herbaceous plants:** | |
| Amaranthaceae | 1 |
| Compositae | 3 |
| Cyperaceae | 2 |
| Poaceae | 4 |
| *Rumex* | 1 |
| **Number of identified pollen grains:** | 102 |
| **Pteridophyte spores:** | |
| *Osmunda* | 1 |
| Monolete spores without perispore | 15 |
| Trilete Spores | 3 |
| Other spores | 15 |
| **Bryophyte spores:** | 206 |
| **Fungal spores:** | 12 |
| **Dinoflagellate cysts:** | |
| *Lingulodinium machaerophorum* (coast to lagoon) | 1 |
| *Pentapharsodinium dalei* (lagoon) | 1 |

*Table 1: Result of palynological analysis of a clay sample from the Petit Odieux Cave.*

# 5. Discussion and conclusion

The Dévoluy Massif is the highest Subalpine massif in the French Western Alps, and it was periodically glaciated during the Pleistocene. Mid-late Miocene sediments were not reported in the Dévoluy Massif up to nowadays; thus, there is no surface equivalent to the allochthonous deposits investigated in the Obiou caves. Therefore, our

paleoenvironmental reconstruction based on palynological analysis from cave deposits is a first attempt to infer mid-late Miocene conditions for the Dévoluy Massif and the Southern Ecrins sector. The evidence suggests humid and warmer conditions than nowadays (e.g., presence of subtropical plants), with probable important runoff. These conditions agree with warm climate well stated in Western Europe during the Miocene by previous works (e.g., SUC *et al*., 2018). Some subtropical taxa like *Cathaya* are now absent from Europe, and they can be found in mountainous regions of Southern China. Our pollen assemblage resembles to Tortonian pollen flora identified in the study of FAUQUETTE *et al*. (2015), from foreland basins located further south. The karst base-level related to the caves would be at low elevation, as suggested by the presence of subtropical trees and probably close to sea-level (e.g., dinoflagellate cysts). Thus, we suggest that these studied caves located presently at high altitudes would be formed close to a coastal plain, which had a low hydraulic gradient and was periodically flooded during the mid-late Miocene. Allochthonous deposits - (pebbles, sands and clays) were originated from the Ecrins catchment (Pelvoux ECM) drained by the paleo-Drac River. The pollen assemblage representative of different vegetation belts, suggests a high relief in the Ecrins sector already established since the mid-late Miocene. The presence of *Picea* would suggest an initial elevation of at least 1900 m. This altitude may be even higher in the case of a complete altitudinal belt of *Picea* forest (elevation amplitude of 700 m). Coastal conditions during the mid-late Miocene in the Dévoluy area have not been documented so far, probably due to lack of a sedimentary record. However, mid-late Miocene marine molasses are well-preserved in the Vercors and Bas Dauphiné (KALIFI, 2000). Our findings suggest that there was an extension of this mid-late Miocene sea ~40 km southwards in direction to the Dévoluy region. The Obiou Peak would already have constituted significant topography at that time, standing at least 400 m above the coastal plain and would represent a nascent subalpine massif. Consequently, the paleo-Drac River would have shaped the caves (or at least the Jalabres Cave with its meander), and deposited alluvial infill inside the karstic conduits. At present, the Obiou caves are perched at an altitude range of 2250-2370 m, indicating a significant uplift of at least ~2000 m, since the mid-late Miocene. The mechanisms and timing of such uplift remain yet insufficiently constrained and need to be extensively investigated with additional studies in the future. Our contribution on quantifying and dating the Dévoluy uplift is still a new approach and shows that palynological investigations in cave deposits located in highly erosional environments display a certain potential in deciphering past geodynamics. It will be more robust with additional pollen samples and once combined with other types of investigation on cave deposits.

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