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Lateglacial/Holocene environmental changes in the Mediterranean Alps inferred from lacustrine sediments

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A B S T R A C T

This study investigates sediment cores from the Mediterranean alpine lakes located in upvalley cirques upper than 1700 metres a.s.l. using sedimentological, palynological and geomorphological studies, in order to document environmental changes following the last phase of glacier retreat. These results are considered in the framework of the deglaciation characterized from 16 sediment cores from high-altitude lakes and mires including 104 ^{14}C ages and geomorphological studies of the Mediterranean Alps. Considering each sediment core proxy as an independent observation, i.e., comparisons between ^{14}C ages and palynostratigraphy, between ^{14}C ages and lithostratigraphy, between palynostratigraphy and lithostratigraphy, these data are aimed at contributing to a better understanding of the timing of postglacial environmental changes. The ^{14}C ages combined with pollen biostratigraphy indicate that the deglaciation of cirque catchments is dated between 14,500 and 13,000 cal. BP, i.e., during the Lateglacial Interstadial (Greenland Interstadial-1e). The sixteen lacustrine and mire sediment records are systematically characterized by three units from bottom to top: organic-poor blue clay, beige to light-brown silty clay and organic rich dark brown gyttja lithotype. During the Younger Dryas, lakes located below 2300 m a.s.l. were ice-free and their pollen record indicates steppe conditions. The sedimentary facies also informs on the timing of glacial-dominated processes. The onset of organic-rich gyttja is dated at 11,000 cal. BP suggesting the last influence of cirque glaciers in these lakes at the beginning of the Holocene. The timing of the onset of this organic rich unit differs in sites (±2000 years) probably due to an altitudinal and exposure gradient of the glacial cirques. The presence of gyttja from 11,000 cal. BP to Present indicates biogenic infilling lake for all the Holocene. Even though the literature have indicated rock glacier advances occurred during the Holocene (Subboreal and LIA) in the south of the Alps, no significant sedimentological patterns related to glacier fluctuations are recorded in Lake Vens. The glacier fluctuations in the Mediterranean Alps are concomitant with those dated in the non-Mediterranean Alps, thus suggesting a main common climate forcing. However, the increase in terrigenous sediment inputs since 1800 cal. BP is mainly due to human activities.

1. Introduction

Significant advances have been made over the last few decades in understanding the chronology of alpine glacier retreat and associated Holocene palaeoenvironmental changes. The transition between the Last Glacial Maximum (LGM) and the Holocene is a

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key time interval that provides contrasting boundary conditions for terrestrial ecosystems response with episodes of insolation changes and ice melting. At the end of the Pleistocene and consecutively to alpine glacier retreat, new ecosystems (soil, vegetation, and fauna) developed on freshly ice-free valleys; profoundly modifying mountain landscapes (e.g., Tinner et al., 1996; Heiri et al., 2003; Lotter and Birks, 2003). However, the timing of these changes (e.g., synchronism, delay) is poorly known, notwithstanding the fact that they are crucial to a better understanding of thresholds in the Earth's climatic system (Alley et al., 2003). This is especially true in the southernmost part of the Alpine range, especially the Mediterranean Alps, since there is a lack of *in situ* landform dating and a dispersed corpus of lake sediment studies. The Mediterranean Alps are a privileged environment for investigating landscape and climate change since the Postglacial because: (1) strong altitude (several summits attain 3000 m a.s.l.), climate and ecotone gradients amplify responses to climate change and, (2) the proximity of the Mediterranean Sea (less than 30 km) provides a good context for studying the effects of European and Mediterranean climatic influences.

In this context, lake sediment sequences have been studied to constrain the trends and the timing of glacier retreat and the subsequent Deglacial and Holocene. Since the pioneer studies of de Beaulieu (1977), very few sediment cores from the Mediterranean Alps concerning the last 20,000 years (Lotter and Birks, 2003) have been studied. Most of the well-preserved long-term archives are high-altitude lakes and mires sediments in inherited glacial cirques located behind glacial steps. Most studies of postglacial sediments in the Mediterranean Alps combine three independent analyses: (1) sedimentological descriptions, (2) palynological analysis and (3) radiocarbon dating, providing a biostratigraphical framework used to constraint periods of cirque glacier activity. Due to the lack of terrestrial macroremains in these high-elevation environments, one of the main issues is dating the early stages of deglaciation: inconsistencies in some radiocarbon age sets require a re-evaluation of the radiocarbon framework (Pallàs et al., 2006). Palynology is a powerful tool for Quaternary chronostratigraphy. The richness of palynological studies in the Alps provides a well-documented and well-constrained biostratigraphical framework based on plant taxa expression into pollen diagrams and vegetation changes (Van der Knaap et al., 2005). Thus, the palynostratigraphical framework can support radiocarbon dating of glacial features and of lacustrine sediments to reconstruct the chronological framework of postglacial environmental changes over the Mediterranean Alps.

In this study, we use a multi-proxy approach involving sedimentological and palynological analysis, as well as ^{14}C dating, to document environmental changes starting from the early phases of lake development and infilling through to glacier retreat from the Lateglacial to the Holocene period. We first conduct a synthesis of 15 published and unpublished studies of high-altitude lake and mire sediment records, and then follow up with the sedimentological and palynological analysis of a sediment record of Lake Vens (2330 m a.s.l.) located in the French Maritime Alps. On the basis of comparisons between: (1) ^{14}C ages and palynostratigraphy, (2) ^{14}C ages and lithostratigraphy, and (3) palynostratigraphy and lithostratigraphy, these new results throw further light on existing climatic datasets of this region. These three approaches provide interesting perspectives to investigate postglacial environmental changes in the region. The aims are: (1) to review the glacial and deglacial geomorphological evolution in the Mediterranean Alps, (2) to reconstruct phases of the palaeoenvironmental variability at Lake Vens and to establish a chronology for the sediment core using a combination of radiocarbon ages and palynostratigraphy and (3) to interpret these new results in the framework of the deglaciation chronology at the scale of the Alps.

2. The Mediterranean Alps

The study area is located between latitudes 44.4°N and 44.0°N and lies astride mountain cirque catchments of the Southern Alps (Fig. 1): the Upper Eastern Durance (UED) and the French and Italian Maritime Alps (FMA and IMA). The mean altitude is about 2000 m a.s.l. and the highest peaks reach elevations of 3000 m a.s.l. The UED is drained by the Durance, Ubaye and Verdon Rivers. The Maritime Alps are drained by the Var, Tinée, Vésubie and Roya Rivers on the French side and by the Gesso and Stura di Demonte Rivers in the Italian side (Fig. 1).

Due to the short source-to-sink distance, sharp topographic contrasts provide favourable conditions for steep-side cutting, narrow valleys and canyon development. The relief can be summarized in a two-step topographic profile: dissected mountains crests are characterized by vertical rock bars overhanging small smoothed glacial cirques, which in turn overhang their main fluvial valleys by steep slopes of 25°–45°. The geology of the Maritime Alps massif consists mainly of granitic basement rocks and Permian sandstones. Vast areas of sedimentary rocks, composed of conglomerates and evaporites, occur on the southern and western flanks of the massif. In the UED, the lithology consists of sedimentary terrains forming the limestones of the Ubaye-Embrunais thrust-sheets and Cretaceous flysch, Aptian–Albian black shales, Upper Cretaceous limestones, and Annot sandstones. Quaternary deposits consist in alluvial deposits and slope colluviums between 1000 and 2000 m a.s.l. As a result of the steepness and sediment cover of these slopes, numerous landslides have occurred on the flanks of the main valleys (Julian and Anthony, 1996).

The vegetation consists of Mediterranean plants tolerant to altitude and plants having affinity with a cool and humid climate. The intra-alpine low-altitude vegetation belt (500–800 m a.s.l.) is dominated by a diversified oak forest (mainly pubescent oak). Cultivated trees such as chestnut and olive trees are common on south-exposed slopes of the intra-alpine valleys. The mountain vegetation belt (800–1500 m a.s.l.) exhibits a strong asymmetry in conifer forest between the southern and the northern slopes. Scot pines dominate drier southern slopes whereas wetter northern slopes are favourable to the development of fir-spruce forests regularly associated with beech trees. Vegetation in cirque valleys is characteristic of the sub-alpine belt (1500–2200 m a.s.l.). Larch trees are sparsely distributed on slopes. This more open landscape is dominated by dwarf species such as juniper, blueberry shrubs and rhododendron. The upper limits of forest attain 2200 m on the northern slopes and 1900 m on the southern slopes. Beyond 2200 m a.s.l., the alpine vegetation belt is dominated by the herbaceous species of alpine meadows.

A major aspect of the climate of this alpine mountain setting is the influence of the Mediterranean. At 1800 m a.s.l., the climatic regime is typical of the northern Mediterranean (dry summers and mild winters) and influenced by altitudinal gradients. In both the FMA, the IMA as in the UED, air temperatures are generally higher than in the northern Alps and snow cover duration is shorter. The mean annual air temperature at 1800 m a.s.l. is 5 °C, varying from 0.3 °C in winter to 9.9 °C in summer (Durand et al., 2009). The study area shows relatively high mean snow thickness values at all altitudes due to rather high amounts of moisture from the nearby Mediterranean Sea (Durand et al., 2009). Snow cover duration in the study area is 140 days at 1800 m a.s.l. and 185 days at 2100 m a.s.l. A strong precipitation regime characterised by a NW–SE asymmetry differentiates the Maritime Alps and the UED in terms of climatic domains. The FMA and the IMA are characterized by higher mean annual precipitation (1340 mm) than the UED (1200 mm). The contrast in precipitation regime is stronger during summer when precipitation occurs as rainfall. The southeast flanks