Mid- to Late Holocene in the Dolomites (Eastern Italian Alps): climate and environmental dynamics inferred from pollen and geochemical analyses

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The Dolomites have been declared UNESCO heritage (2009) and host a sensitive ecosystem, which is endangered by the ongoing climate warming. In fact in the European Alps an increase of about 2°C has been registered in the last century, which is twice as the average for the Northern Hemisphere. Despite their importance, in the Dolomites there is a lack of high resolution multi-proxy palaeoclimatic studies that needs to be filled.

Coltrondo peat bog

- Located at 1800 m a.s.l. in the Eastern Italian Alps (46°39' N 12°26' E)
- A 2.5 m depth core was retrieved and subsampled with a 1 cm resolution
- The core covers the last 7900 years; the age-depth model was performed merging ^{14}C and ^{210}Pb dates (**Fig.1**)
- Trophic status: physical and chemical analysis (LOI measurement, pH of pore water and Ca/Mg ratio in pore water and precipitation) assess the ombrotrophy of the mire
- A multi-proxy approach including pollen, physical and geochemical analyses was adopted

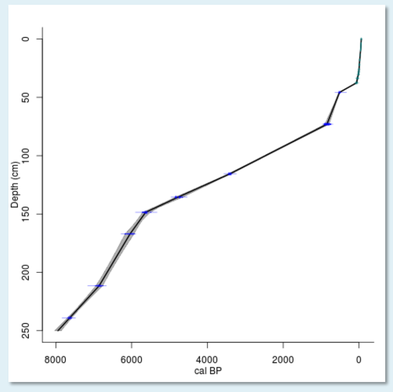
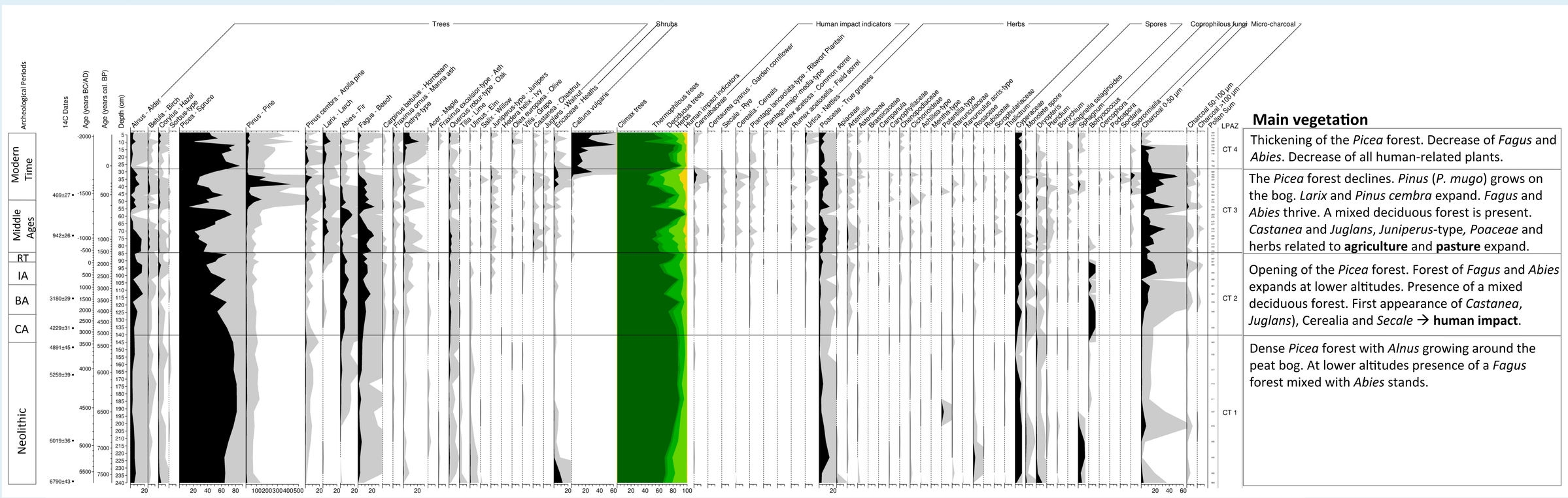


Fig. 1 - *Clam* age-depth model

Aim of study

The aim of the study is to gain palaeoclimatic and palaeoenvironmental information for a better understanding of the climatic history of the area and inter-relationship between the environment and the climatic system. The multi-proxy approach adopted allows to explore different facets of the ecosystem and to trace different kinds of human impacts.

Pollen analyses: climate dynamics and human impact

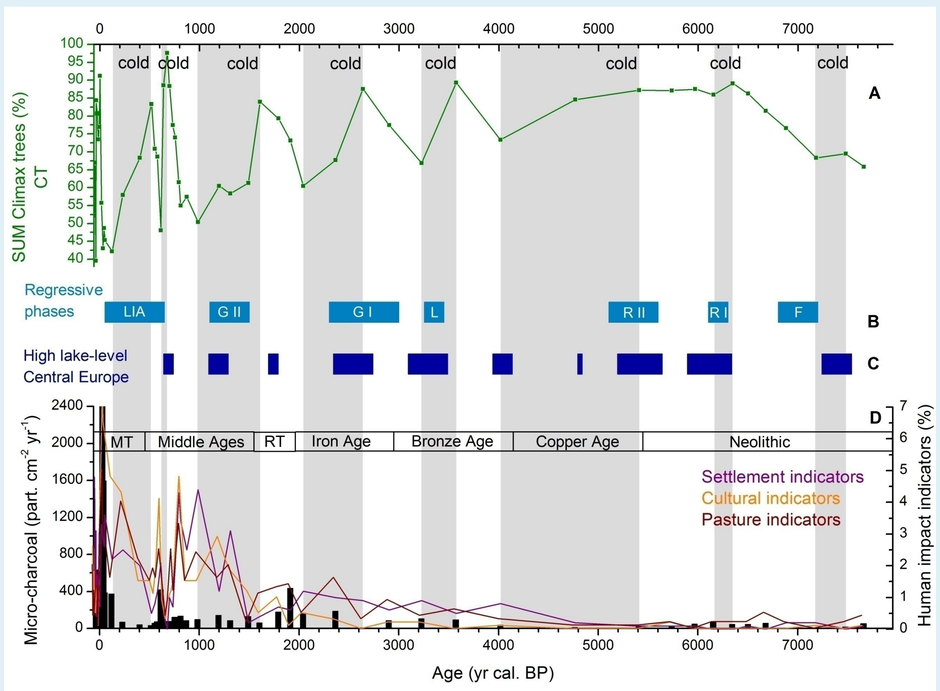


Main vegetation

CT 4	Thickening of the *Picea* forest. Decrease of *Fagus* and *Abies*. Decrease of all human-related plants.
CT 3	The *Picea* forest declines. *Pinus* (*P. mugo*) grows on the bog. *Larix* and *Pinus cembra* expand. *Fagus* and *Abies* thrive. A mixed deciduous forest is present. *Castanea* and *Juglans*, *Juniperus*-type, *Poaceae* and herbs related to **agriculture** and **pasture** expand.
CT 2	Opening of the *Picea* forest. Forest of *Fagus* and *Abies* expands at lower altitudes. Presence of a mixed deciduous forest. First appearance of *Castanea*, *Juglans*), Cerealia and *Secale* → **human impact**.
CT 1	Dense *Picea* forest with *Alnus* growing around the peat bog. At lower altitudes presence of a *Fagus* forest mixed with *Abies* stands.

Fig. 2 - Simplified pollen diagram, percentage values are shown; CA = Copper Age, BA = Bronze Age, IA = Iron Age, RT = Roman Time

In **Figure 3** the climax community vegetation curve **(A)** is compared with other climatic proxies recording cold events in the Alps, glaciers advances **(B)** and high lake levels **(C)** → the main climatic oscillations of the Middle and Late Holocene are registered in the pollen profile.

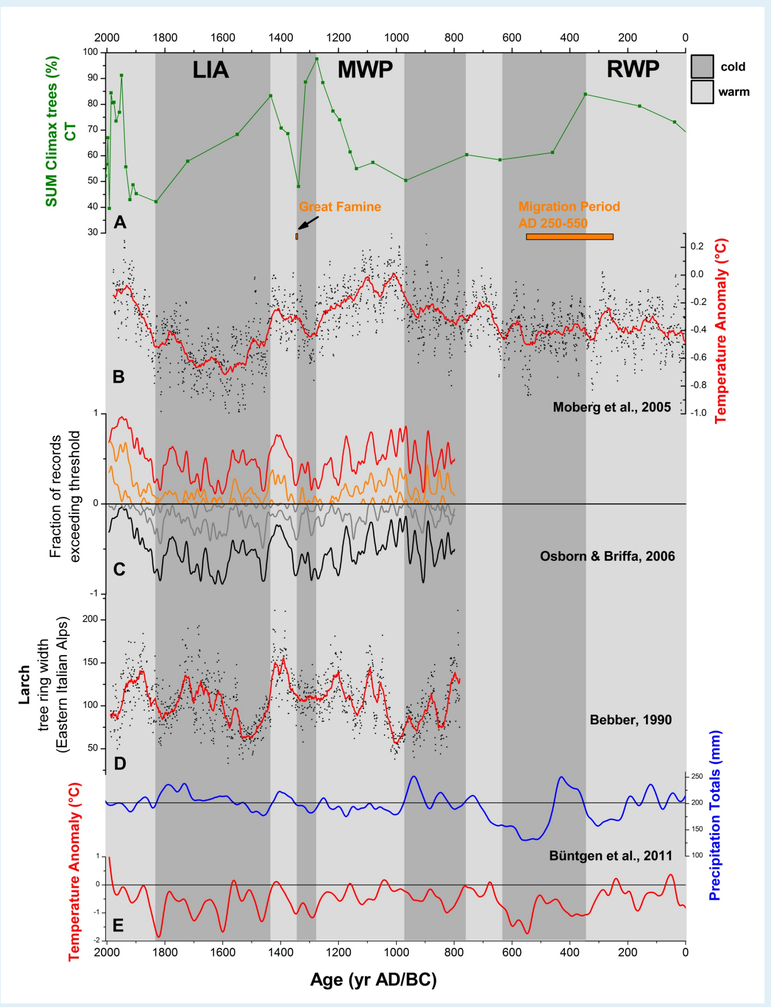


▲ **Fig. 3** – Comparison of the Coltrondo peat bog climax communitiy **(A)** with other palaeoclimate records (B,C). **(B)** Main alpine glacier advances during the Little Ice Age (LIA), Göschener I and II (GI and GII), Löbben (L), Rotmoos I and II (RI and RII) and Frosnitz (F) cold oscillations (Ivy-Ochs et al., 2009). **(C)** Lake-level high stands in Central Europe (Magny, 2004). **(D)** Micro-charcoal particles and human impact indicators from the Coltrondo peat bog; MT = Modern Time, RT = Roman Time

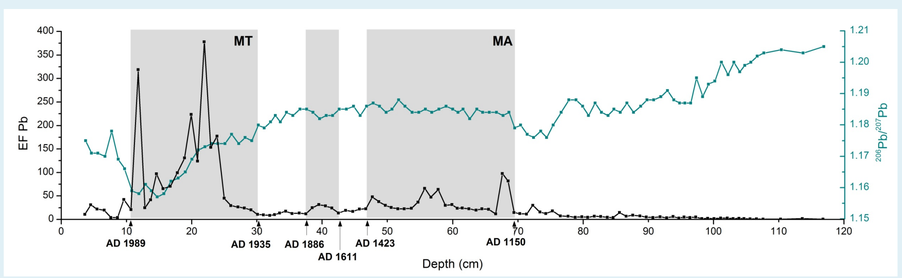
Human interferences (**Fig. 3D**) start from the Bronze Age, increasing in the Iron Age and the Roman Time, showing a peak during the Middle Ages. Settlement, pasture and agricultural activities are registered in the pollen diagram, giving new insight in the man's history of this area where archeological remains are scarce.

Figure 4 is focused on the last 2000 years: a clear relation between the climax community pollen percentage **(A)** and temperature and precipitation reconstructions for Northern Hemisphere **(B, C)** and Europe **(D, E)** is visible.

► **Fig. 4** – Focus on the last 2000 years. The climax communivity **(A)** is compared with temperature and precipitation reconstructions from other palaeoproxies (B-E). **(B)** Northern Hemisphere temperature reconstruction (Moberg et al., 2005). **(C)** Positive and negative deviations of temperature-sensitive proxy records from the series mean (= 0) (Osborn&Briffa, 2006). **(D)** Larch tree rings width in the Eastern Italian Alps (Bebber, 1990). **(E)** Summer temperature and precipitation reconstruction for central Europe (Büntgen et al., 2011)



Geochemical analyses: anthropogenic heavy metal pollution



Lead total concentration and lead isotopes were determined for the last 3600 years, with ICP-MS.

Fig. 5 – Enrichment factor of Pb (EF Pb, black line) and $^{206}Pb/^{207}Pb$ ratio (green line) are shown. EF Pb = $(Pb/Ti)_{sample}/(Pb/Ti)_{UCC}$, where UCC = Upper Continental Crust) → number of times a sample is enriched in Pb compared to the natural values. $^{206}Pb/^{207}Pb$ ratio → related with changes in lead supply, from natural sources to anthropogenic ones (mining, coal burning, leaded gasoline...). Grey bars underline EF Pb peaks during the Middle Ages (MA) and Modern Time (MT)

Middle Ages: characterized by several peaks of EF Pb and a $^{206}Pb/^{207}Pb$ ratio (~ 1.85) below the natural values (~ 1.20), probably due to mining activities in the area as evidenced by historical sources (De Lorenzo, 1999).
Modern Time: steep decrease in the lead isotopes ratio coeval with the major EF Pb peaks, related to the ongoing mining activities in the area (Salafossa and Argentiera mines), the Industrial Revolution and the introduction of leaded gasoline.
End of the 80s: lead isotopes ratio starts to increase due to inactivity of the mining sites, the banning of the leaded gasoline in Europe and the increasing attention to atmospheric pollution in Europe.

Conclusions

- The combination of pollen and geochemical analyses allows to track different kind of human interferences.
- The main climatic oscillations of the Middle and Late Holocene are reflected in the vegetation as outlined in the pollen diagram.
- This proves the suitability of the Coltrondo peat bog for past climate studies.

Future outlooks: Data interpretation is currently ongoing and aims to reach a deeper insight on the climatic history of the Eastern Italian Alps by adding valuable information on the climate dynamics of Dolomites.

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