THE QUATERNARY OF COLOMBIA
climate variability and biome evolution

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Fig. 1

Long Records of Environmental and Climate Change

are crucial to document the series of ice ages that characterise the Pleistocene. While in the northern hemisphere ice sheets expanded and shrunk periodically, in the tropical mountains the altitudinal vegetation distribution shifted downslope during relatively cold glacials and stadials and upslope during relatively warm interglacials and interstadials. This poster focus on development age models for the sediments in the basins of Bogotá and Fúquene (*Fig. 1*), the climate history of the northern Andes and the evolution of its high elevation biota.

The 2,250,000-yr long record from the Bogotá basin

In the Bogotá basin (4°N, 2550 m elevation) 586 m of sediments have been cored. The 2200-sample record of grain size distributions shows changes in sedimentary environments [1]. The pollen record starts at 540 m core depth and samples at 20-cm increments along the core provide a record of 2100-samples [1]. The record of aquatic vegetation reflects changes in water depth. The record of trees, shrubs and herbs shows changes in the vegetation that covered the mountains around the lake.

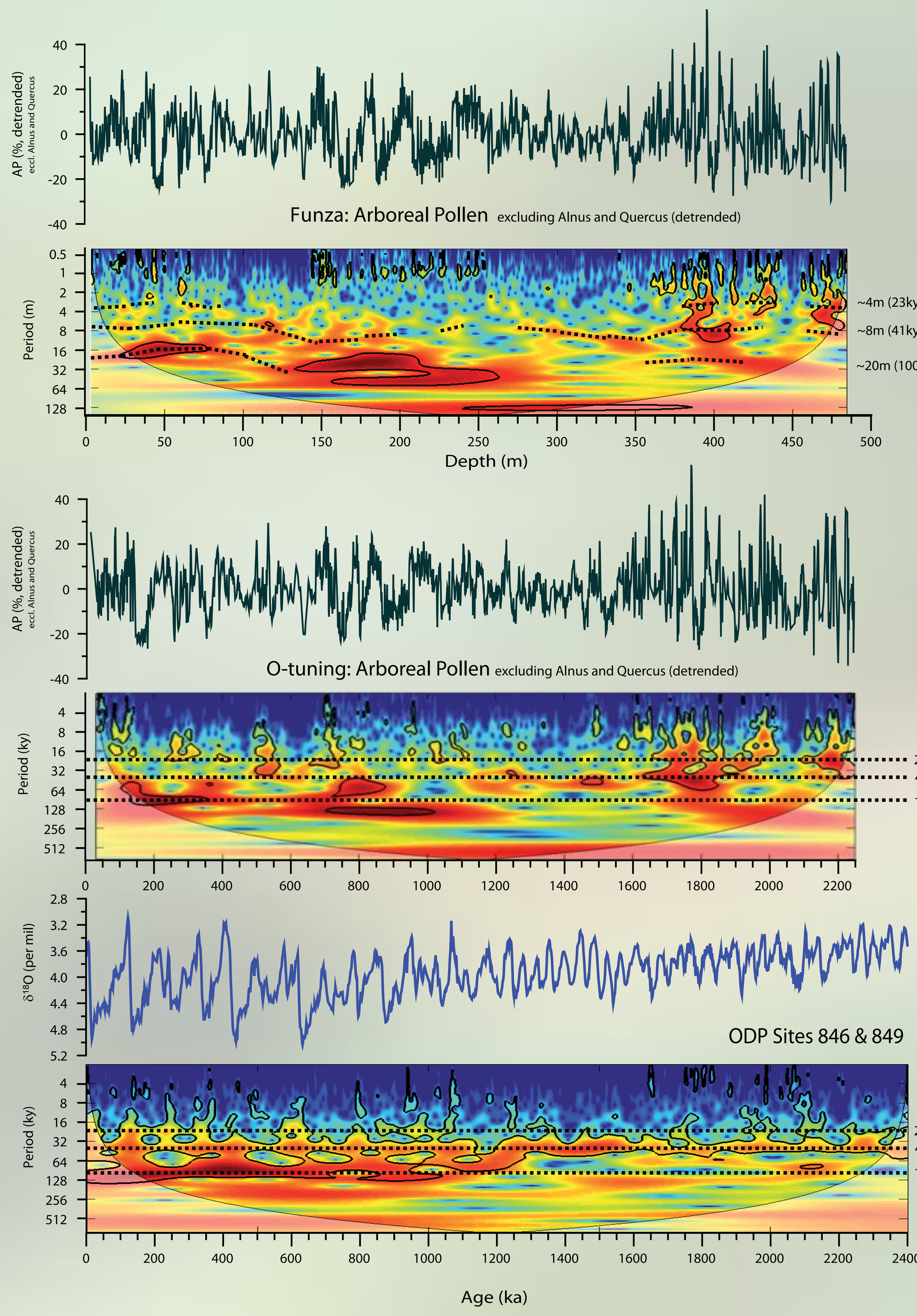


Fig. 4

Age model development

The 357-m deep Funza-1 core [2] and the 586-m deep Funza-2 core [1] have been coupled at the first appearance event of *Alnus* (*Fig. 2*). Changing percentages of arboreal pollen (AP%) in the composite record Funza09 (540-1.6 m) show altitudinal shifts of the upper forest line (UFL) [3]. Using a lapse rate of 0.6°C/100 m UFL displacement and a mean annual temperature (MAT) at the UFL of ~9.5°C paleo-temperatures have been calculated.

During warm interglacial conditions the tree *Alnus* mainly forms swamp forest around the lake reflected as high peaks in the AP% record. The sequence of *Alnus*-based interglacials have been matched with the marine record of glacial-interglacial cycles as shown by the LR04 benthic ∂^{18}O stack record (*Fig. 3*) [4]. The immigration event of *Alnus* has been dated 1.018 Ma. We used cyclostratigraphy to develop the age model for the lower part of the Funza09 record. Frequency analysis in the depth domain shows peaks of 9.5-m and 7.6-m (*Fig. 4*). Wavelet analysis shows a stable presence of the 9-m frequency band which could be robustly linked obliquity as the main driver of climate change. The age model shows the Funza09 record reflects the period from 2,250,000 to 27,000 years BP (*Fig. 5*).

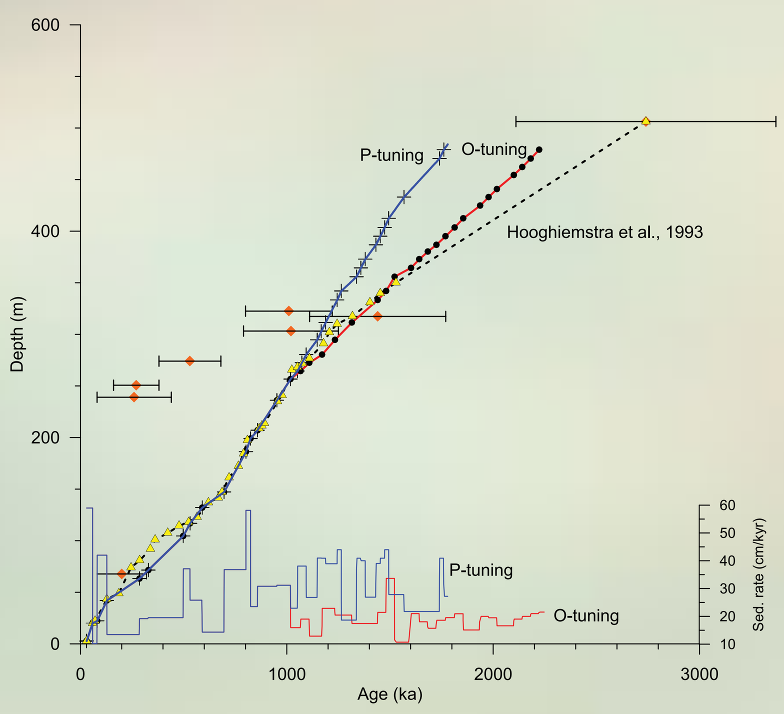


Fig. 5

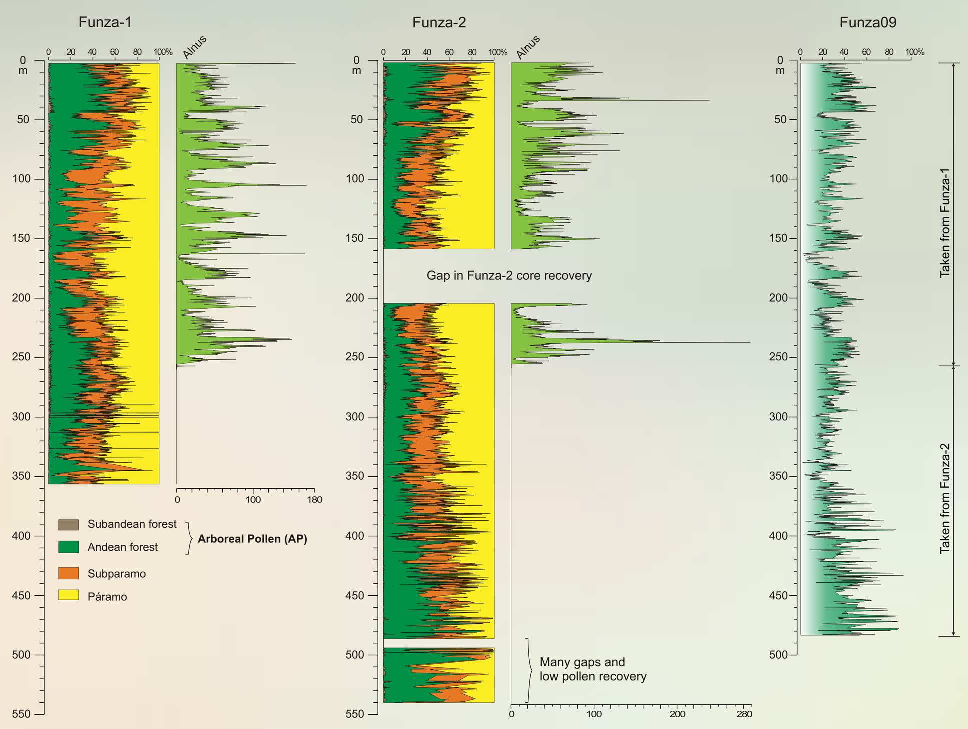


Fig. 2

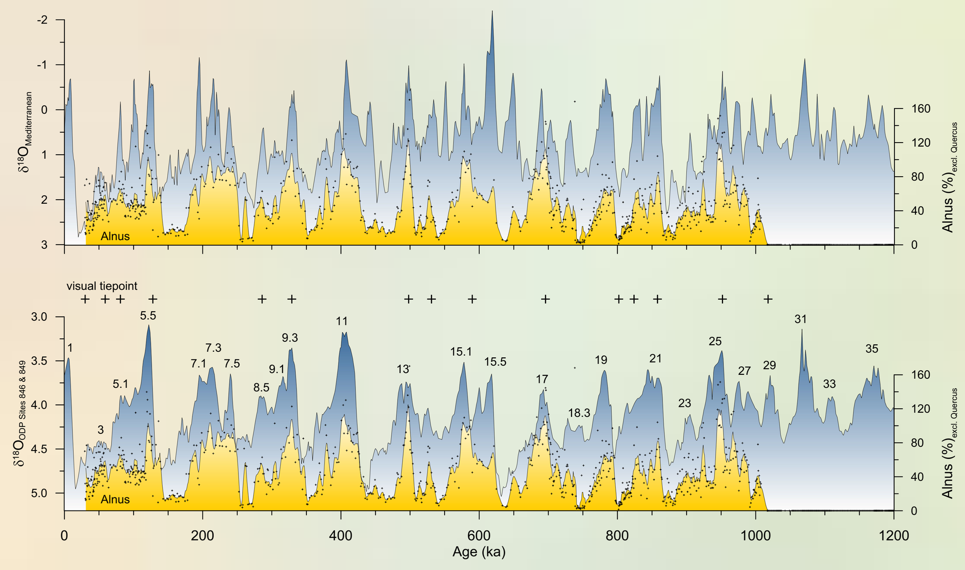


Fig. 3

Basin development

The AP%-based temperature record reflects marine isotope stages (MIS) 85 to 3 (*Fig. 6 lower panel*). The record of aquatics shows deep-water vs. shallow-water conditions reflecting climate change superimposed by effects of basin evolution (*Fig. 6 top panel*). In the period of 2.25-1.47 Ma wetlands, fluvial channels and swamps prevailed. The basin floor subsided rapidly between 1.47 and 1.23 Ma and a lake developed. Between 1.23 and 0.86 Ma lacustrine sediments accumulated in waters up to 50 m deep. Water depth was lower during the last 860,000 years but fluctuated in conjunction with the 100-kyr dominated glacial-interglacial cycles of the middle and late Pleistocene [3]. Around 27,000 BP the lake disappeared probably because the Bogotá basin became overfilled with sediments.

Biome evolution

The Bogotá basin record shows 5 stages in the evolution of montane forest and páramo vegetation (*Fig. 6* middle panels) [3].

(1) Period 2.25-2.02 Ma: vegetation above the UFL was poor in species (protopáramo). *Aragoa* occasionally reached high abundance. In the Andean forest *Podocarpus* increased in abundance. Proper lake conditions had not yet developed. In absence of *Alnus*, *Morella* (*Myrica*) formed swamp forest and thickets on the basin floor.
(2) From 2.02 Ma (MIS 75) onwards increasing proportions of *Aragoa*, Ericaceae and *Hypericum* indicate that shrub vegetation developed as a structural transition zone between upper montane forest and herbaceous páramo. *Polylepis*, originating from the southern Andes, started its presence 2.1 Ma (MIS 78).
(3) From 1.58 Ma (MIS 54) onwards *Borreria* had developed as an element of the upper montane forest and was no longer an exclusive constituent of open vegetation. The páramo reached more closely its modern structure and taxonomic composition. In the montane forest the share of *Podocarpus* decreased.
(4) After the closure of the Panamanian Isthmus several Holarctic trees immigrated into South America. *Alnus* immigrated 1.01 Ma (MIS 29). In the swamp forest around the lake *Alnus* replaced *Morella* (*Myrica*). On the north Andean slopes *Alnus* changed the composition of montane forests.
(5) At 430,000 yr BP (MIS 12) *Quercus* (oak) arrived in the northern Andes and changed forest composition dramatically. At high elevations *Quercus* competed with *Weinmannia* and *Podocarpus*. Near the UFL *Quercus* partially replaced *Polylepis*. However, *Quercus* expanded slowly and reached as late as 240,000 yr BP (MIS 7) significant proportions.

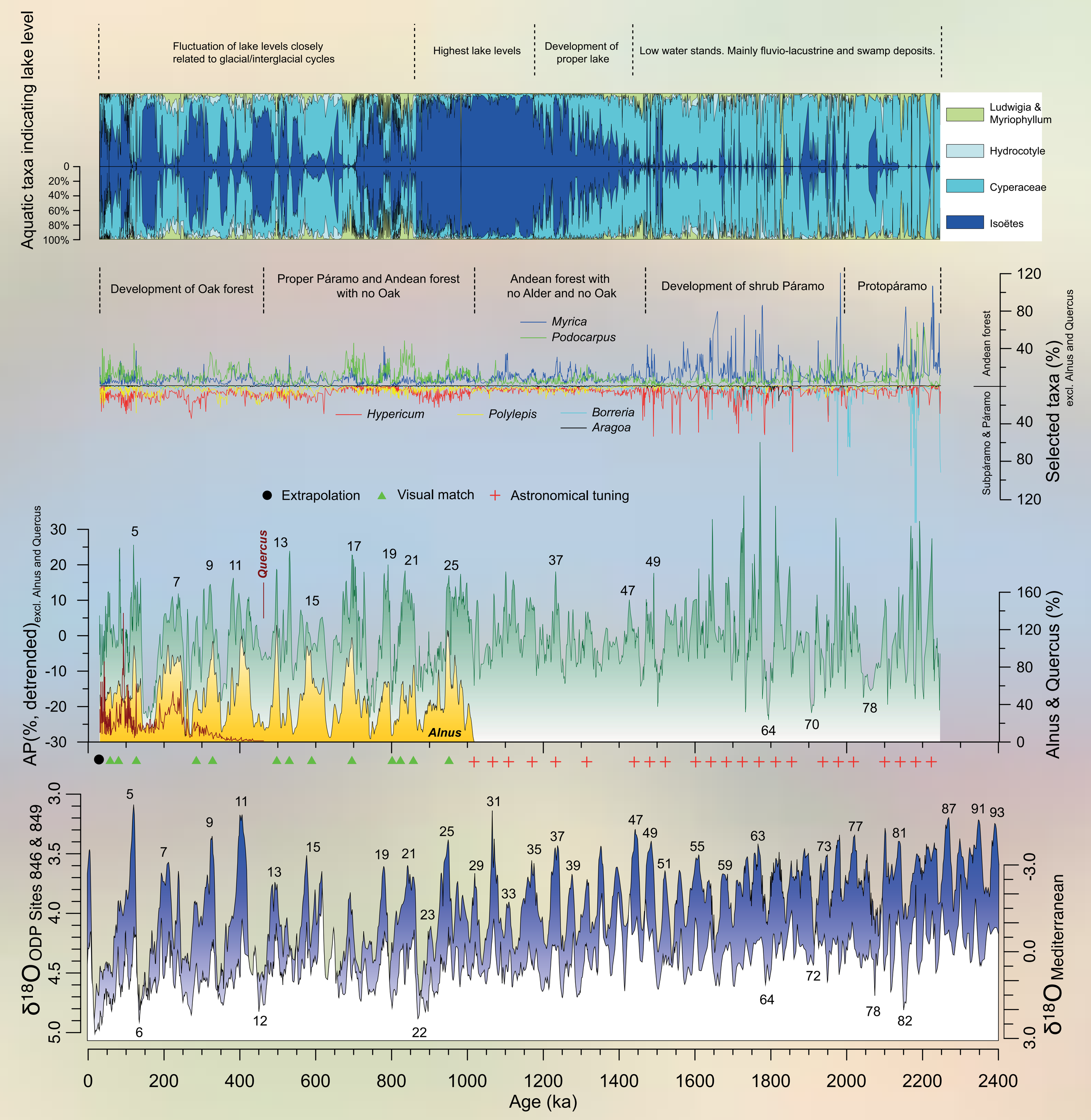
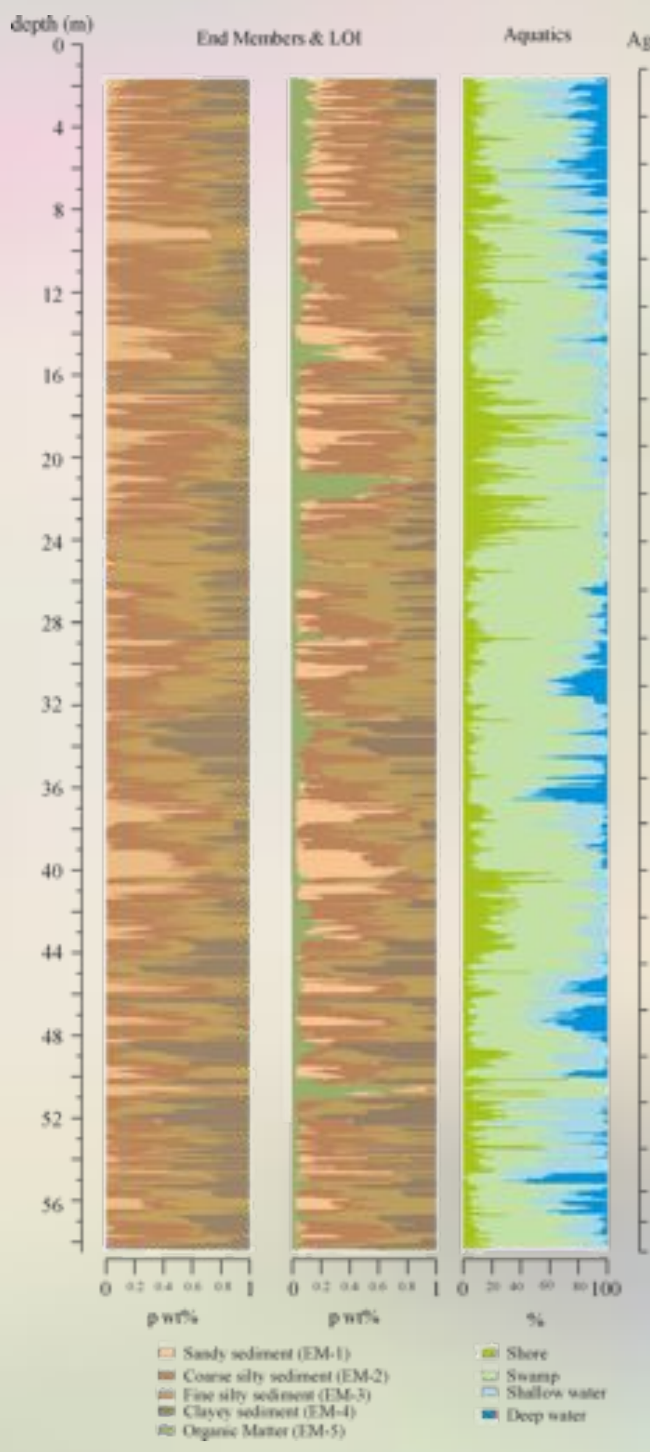


Fig. 6

Most of the Pleistocene vegetation assemblages have no modern analogue. However, modern ecological constraints of suites of taxa allow a robust reconstruction of environmental and climate change.



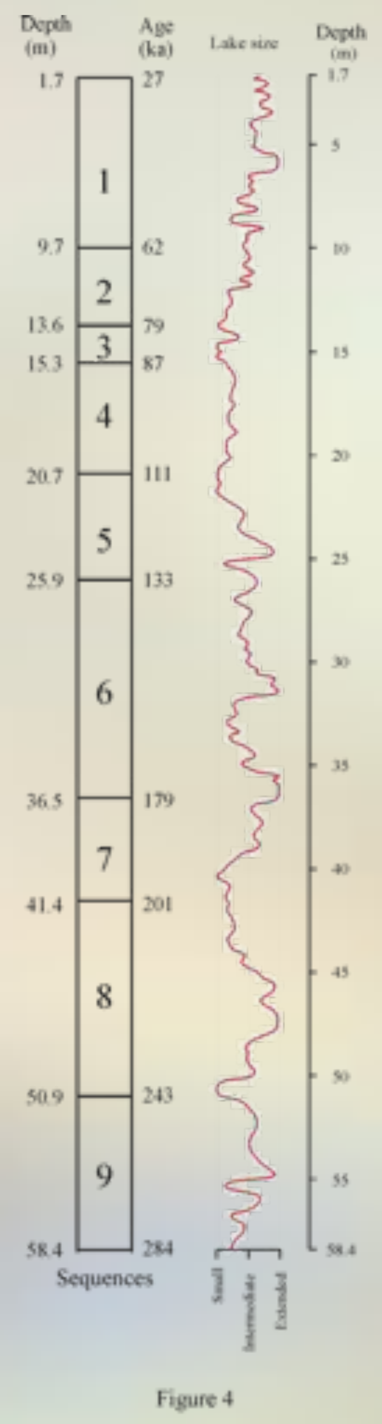


Fig. 7

The 284,000-yr long record from the Fúquene basin

In Lake Fúquene (5°N, 2540 m), a colluvial damm blocked lake [5], the upper 60 m of sediments have been collected from a floating raft in two parallel cores (*Fig. 1*). Downcore measurements at 1-cm increments revealed multiple 4768-points records. Pollen and carbon content show biome changes in the area and grain size distributions and XRF-based geochemistry show the abiotic changes in the basin. Downcore changes in lithology [5], Fe and Zr [6] in cores Fq-9 and Fq-10 allowed to develop the composite record Fq-9C [7]. Geochemical records show changes in erosion and sediment transport in the basin. Downcore grain size distributions show changing sedimentary environments (*Fig. 7*). Downcore aquatic pollen show changes in water-levels (*Fig. 7*). Downcore regional pollen show temperature-driven changes in the altitudinal vegetation distribution.

Age model development

Sediments centrally located in the lake contain low percentages of carbon preventing robust 14C-dating [8]. Cyclostratigraphy is a challenging alternative. Frequency analysis of the AP% record in the depth domain show peaks at 907 and 2265 cm. Wavelet power spectra show that the strengths of these frequencies are stable throughout the core in depth and time. These frequencies were explored and appear to be linked to the obliquity (41-kyr) and eccentricity (~100-kyr) cycles of orbital forcing of climate change (*Fig. 8*). Remarkable is the absence of a clear imprint of the precession-related 21-kyr cycle [7]. *Fig. 8A* shows the Fq-9C AP% record as raw data and *Fig. 8B* as a detrended and interpolated depth series overlain by a ~9 m Gaussian filter. *Fig. 8C* shows the LR04 benthic $\partial^{18}O$ stack record [4] overlain by a Gaussian filter centered at the 41-kyr cycle. We correlated the filtered 9-m signal in Fq-9C to the filtered 41-kyr obliquity-related component of the LR04 benthic $\partial^{18}O$ stack record to develop the age model. The 4768-points Fq-9C record reflects the interval from 284,000 to 27,000 yr BP. The Fq-9C record was extended to late Holocene time by adding part of the Fq-2 pollen record [9]: the Fúquene Basin Composite (Fq-BC) record. The connection with modern instrumental data allows to calculate mean annual temperatures (MAT) throughout the record.

For a comparison of temperature records we show Greenland $\partial^{18}O$ ice core record [10] for the past 180,000 years and the record from Antarctic core Epica Dome C [11] and our near equatorial record Fq-BC (*Fig. 9*) [7]. During the last 130,000 years ice cores show 28 millennial-scale climate oscillations (*Fig. 9*, bottom panel), known as Dansgaard-Oeschger (DO) cycles. Most DO cycles are reflected in equatorially located Fq-BC pollen record (*Fig. 9*, top panel) The clear signature of the Younger Dryas (constrained by 14C dates), and the interstadial DO cycles 8, 12, 14, 19 and 20 in the reconstructed MAT record suggest an unprecedented North Atlantic-equatorial link.

We revisited the age models of pollen records Fq-3 [12, 15] and Fq-7C [13] with the new approach of cyclostratigraphy and we obtained a basin-wide biostratigraphy [15] constrained in time (*Fig. 10*). We recognised periods with distinct sediment compositions [14] and abundance of geochemical elements [6].

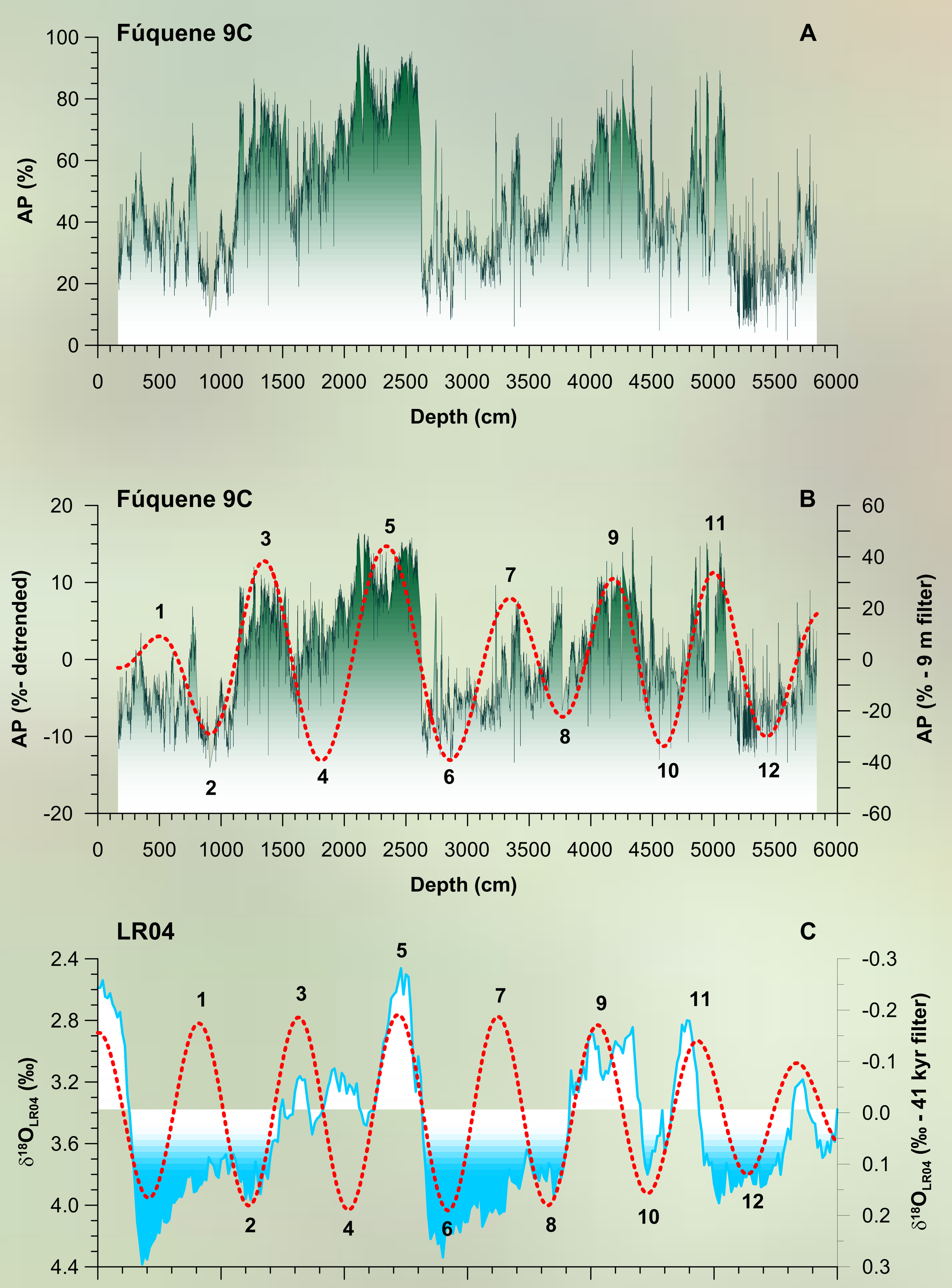


Fig. 8

Conclusions

Tropical montane forest and tropical alpine grassland (páramo) ecosystems are sensitive to variations in global ice volume and respond to global climate change with significant altitudinal migrations. A one-to-one coupling between changes in tropical MAT and the North Atlantic climate variability at both orbital and millennial time scales is shown. Century-scale changes of 2-3.5°C during MIS 3-4 (Pleniglacial) and during previous glacial MIS 6, and extreme changes of up to 10±2°C at the major glacial Terminations are shown. Long continental records analysed at sub-centennial resolution show the dynamic history of terrestrial biomes and allow to assess current and projected future climate change in a Pleistocene framework. However, developing such records is still an academic challenge.

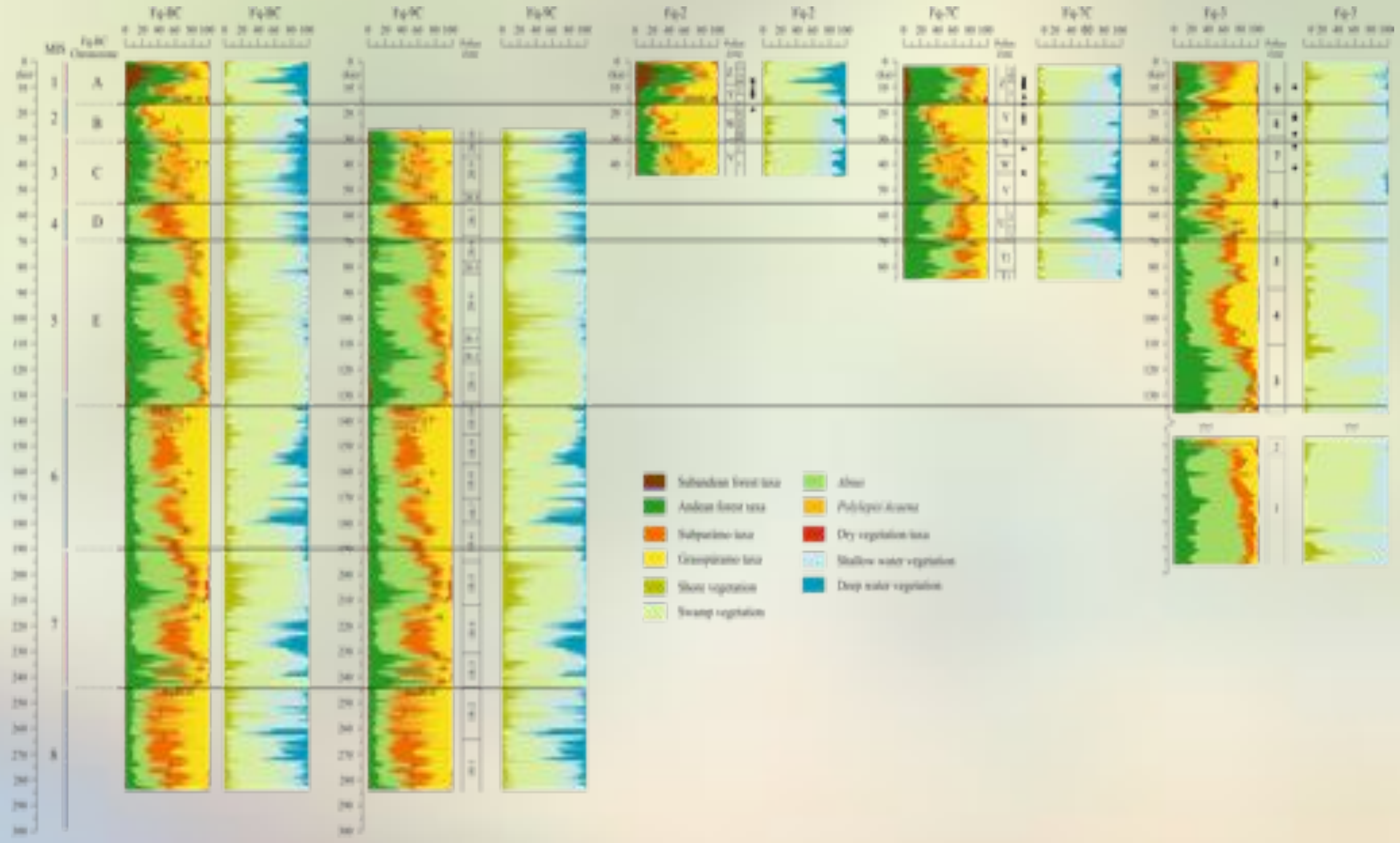


Fig. 10

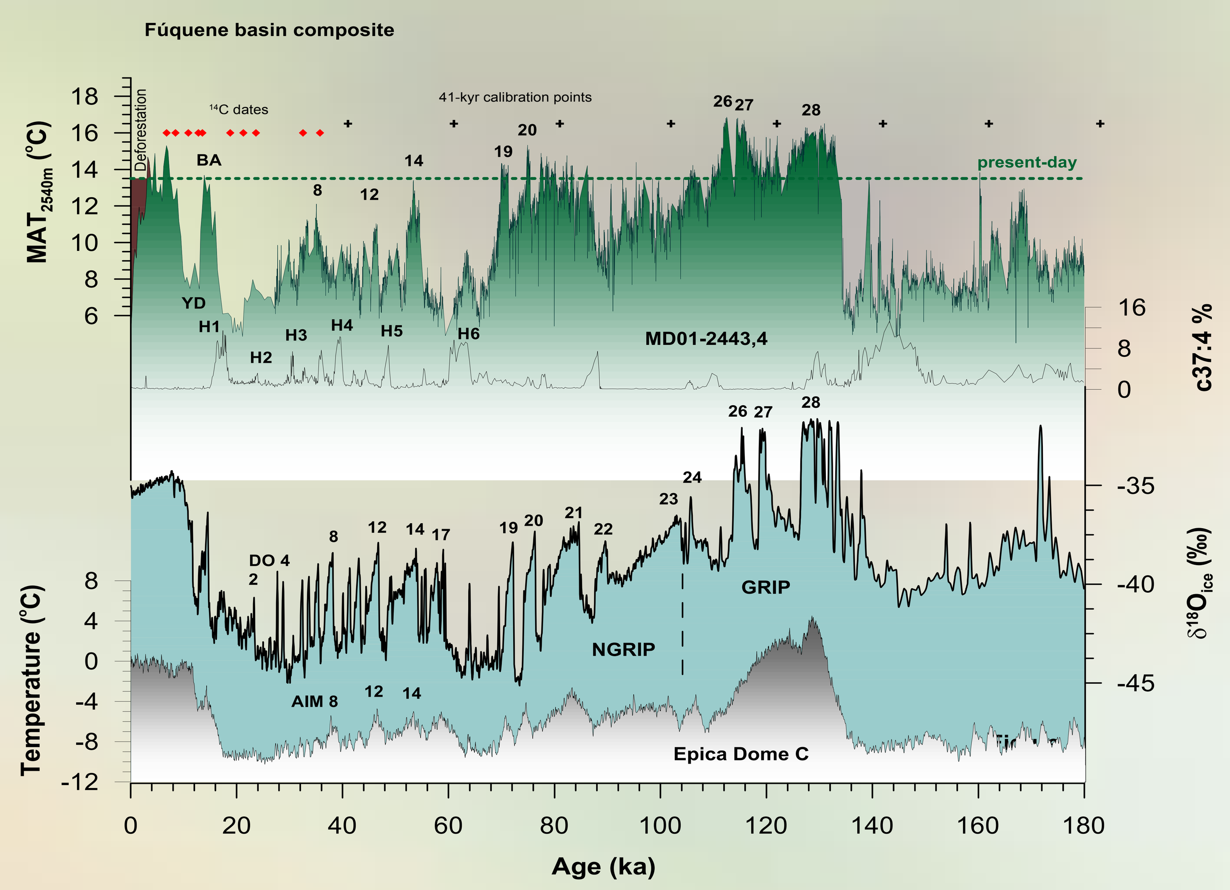


Fig. 9

Acknowledgements

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