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ASSESSING MID-PALEOCENE CLIMATE USING FOSSIL LEAVES

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CONTEXT

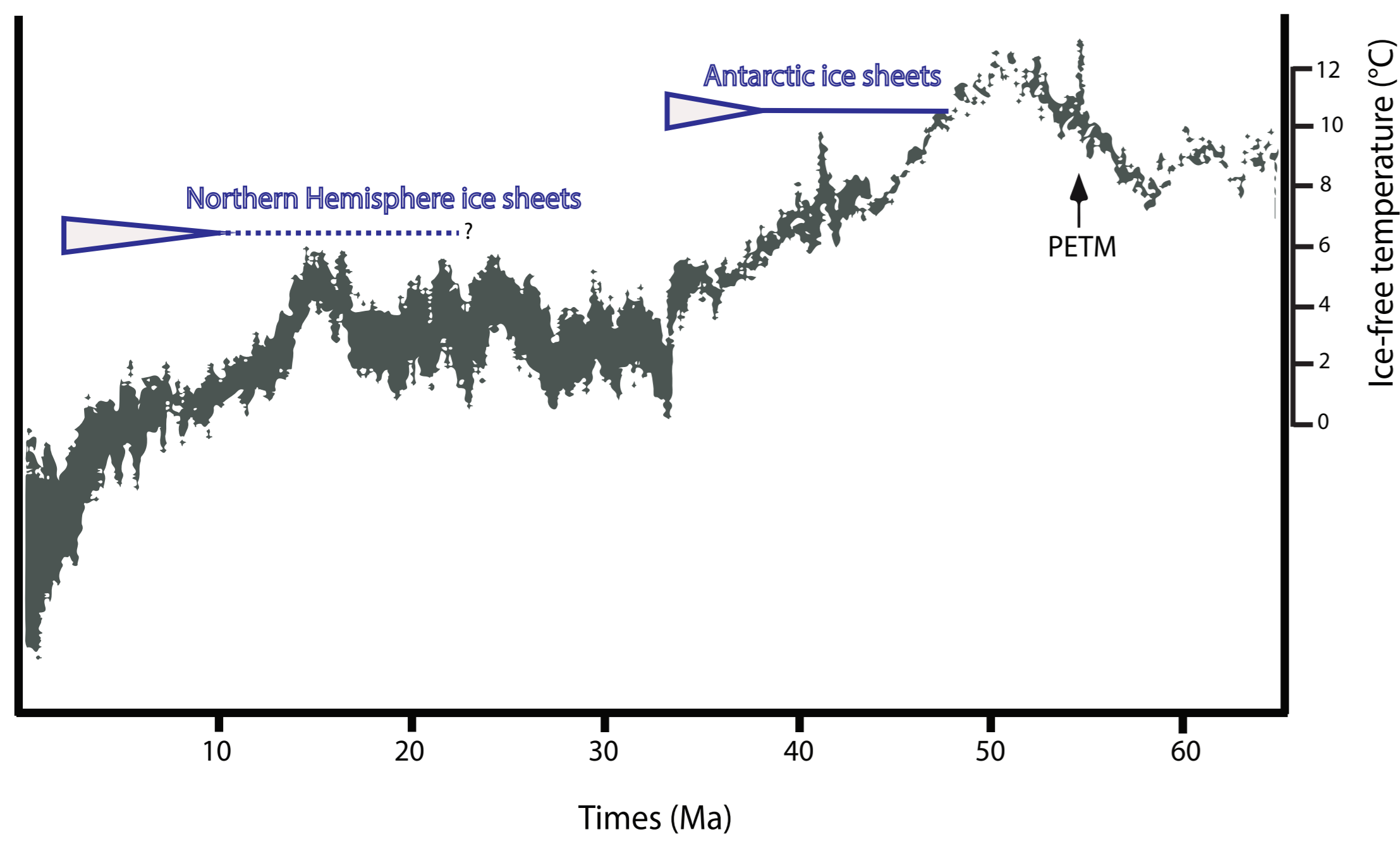


Figure 1. Evolution of sea temperature during Cenozoic, adapted from Zachos et al. 2008

Paleocene climate. — The Paleocene period is famous for its greenhouse climate with estimated pCO₂ range between 450-850 ppm. The evolution of Paleocene climate is now relatively well-known in the marine realm. Data for continental climate are comparatively scarce and most effort has been concentrated on the latest Paleocene - early Eocene tropical climate.

Yet latest studies document the complexity of the climate during mid-Paleocene both for marine and continental record, with the presence of hyperthermal events such as the Mid-Paleocene Biotic Event (MPBE) and a cooler period at the beginning of the Selandian (Dinares-Turell et al., 2007; Kemp et al., 2014, Storme et al., 2014).

Menat and Gelinden historical sites are famous for their well-preserved fossil leaves, representative of typical mid- to late Paleocene forests. These forests were dominated by Lauraceae and Fagaceae, and described as meso- to megathermal floras.

Aim of the study. — This study aims to document mid-Paleocene continental climate in western Europe based on historical collections of fossil leaves using a well-established method (CLAMP). A more recent approach (CLANN) was also tested.

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GELINDEN AND MENAT PALEOFLORAS



Figure 2. Paleomap of western Europe during Paleocene, with localization of the sites (adapted from De Bast & Smith, 2016)

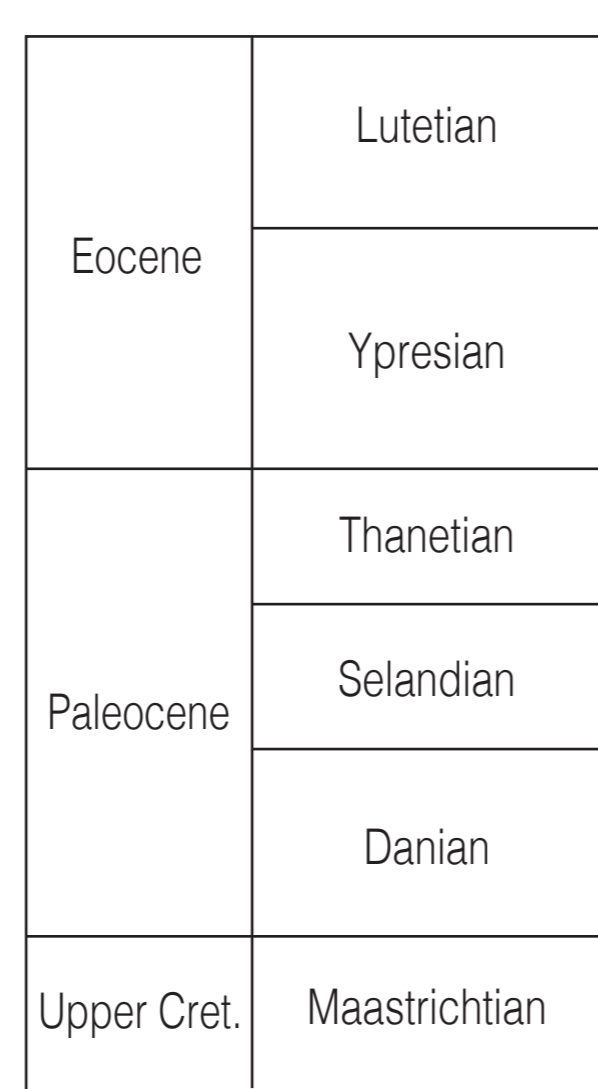


Figure 3. Age of the two localities G: Gelinden, M: Menat.

Gelinden. — **Sedimentology:** shallow-water cyclic marls. **Age:** The age of the Gelinden Mb (Heers Fm) is mid to late Selandian, on the basis of the calcareous nanofossil and dinoflagellate associations (De Bast et al., 2013).

Menat. — **Sedimentology:** laminated, bituminous shales (maar). **Age:** The age of the Menat deposits have been discussed for many years. The last reported age is Selandian based on the presence of *Plesiadapis insignis* (Wappler et al., 2009), however previous studies based on geochemistry and palynology indicated a Thanetian age (Vincent et al., 1977 ; Kedves & Russell, 1982).

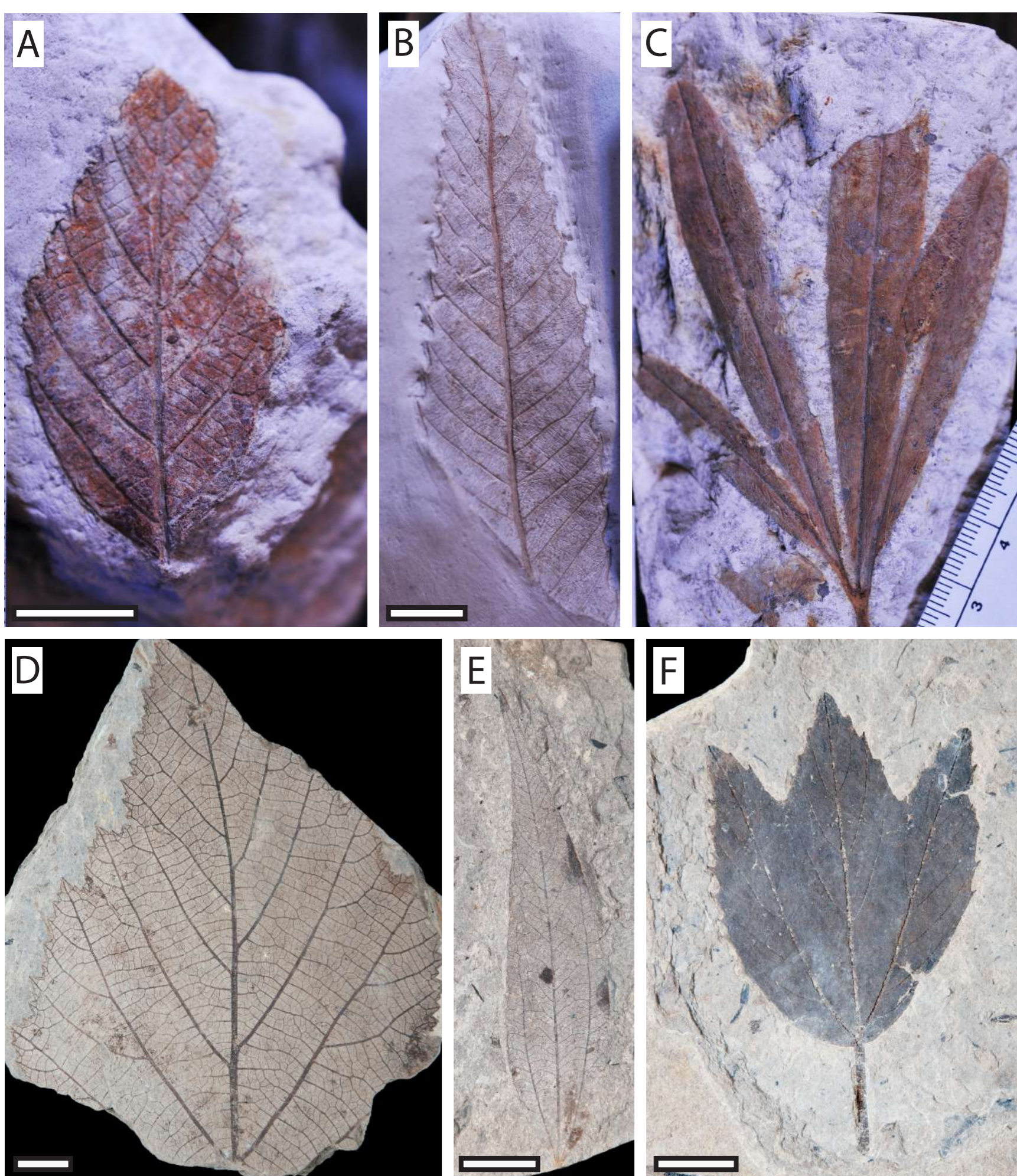
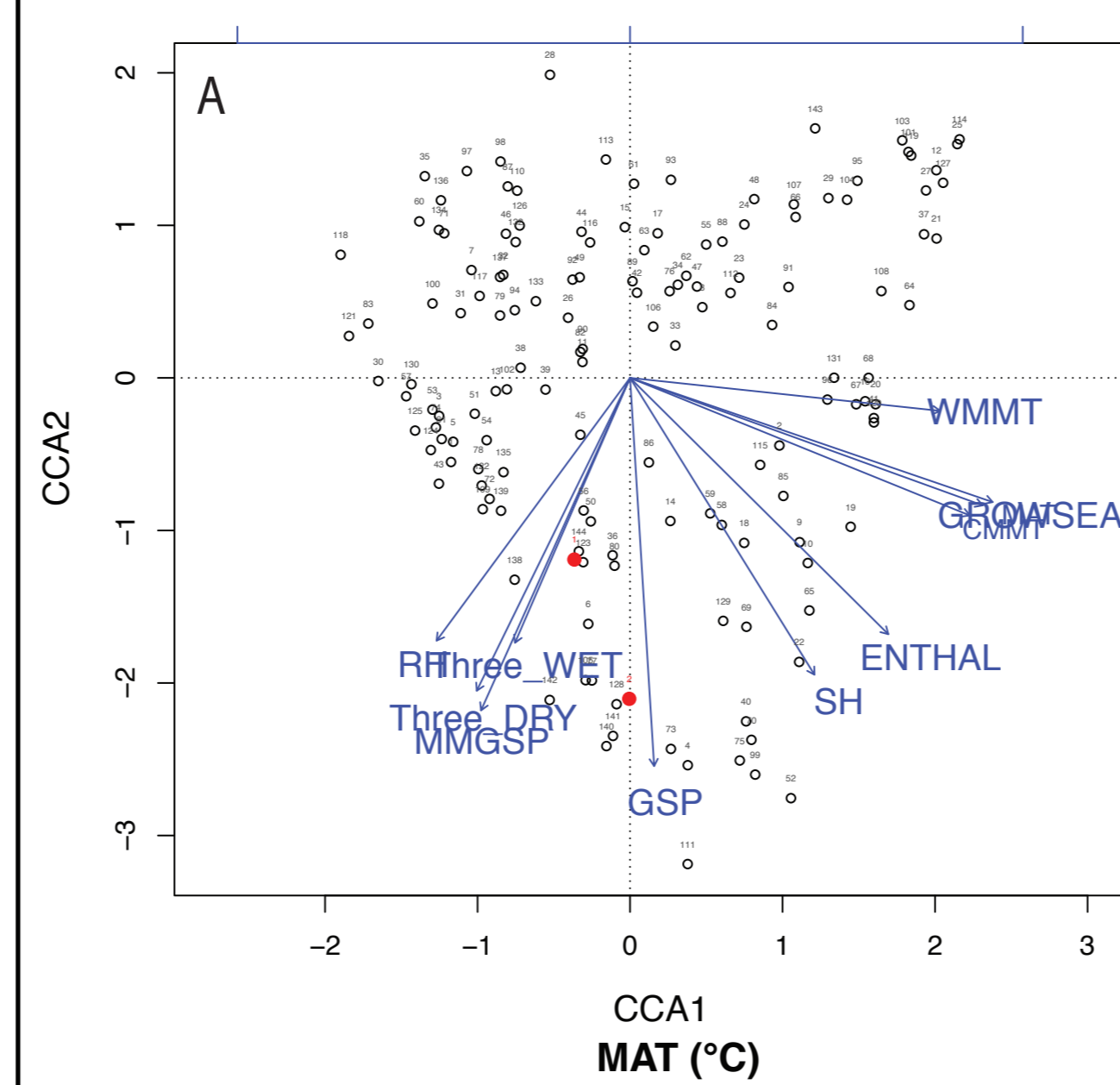


Figure 4. Leaves from Gelinden (A-C) and Menat (D-F). A: *Quercus diplodon*, B: *Dryophyllum dewalquei*, C: *Delwalquea gelidensis*, D: *Corylus macquarrii*, E: *Linderia stenoloba*, F: *Platanus schimperi*. Scale: 1 cm.

Paleobotany. — Both floras belong to the Atlantic Boreal Province (Kvacek, 2010). They are considered as broad-leaved evergreen forests. However, some elements of the polar deciduous forests are described, especially in Menat (e.g. *Platanus schimperi*) which has been characterized as a mixed forest. Taxonomic revision is needed.

PALEOCLIMATIC RECONSTRUCTION



Methods. — CLAMP is based on the use of modern leaf morphology and climate relationship, to infer past climates. Briefly, morphological and climatic data on modern floras are used in a Canonical Correspondence Analysis and form a multidimensional morphospace. The morphology of the paleoflora is then placed among modern morphologies (fig. 5A - red dots) and the paleoclimatic variables are retrieved thanks to the scores of the fossil sites on the climatic linear vectors (fig. 5B-C).

CLANN was developed to account for the non-linearity of the relationship between leaf morphology and climate (Li et al., 2016). Using CLANN as a paleoclimatic proxy leads to wider temperature and precipitation ranges, and higher MAT for both localities (data not shown). This difference is linked to the underlying method (general regression neural network), which uses the leaf morphology - climate relationship of the closest sites (vs all the sites in CLAMP) and thus is very sensitive to variations among sites (Li et al., 2016). This might be a problem when the locality is at the margin or outside of the model, as it is for ancient floras without modern analogues.

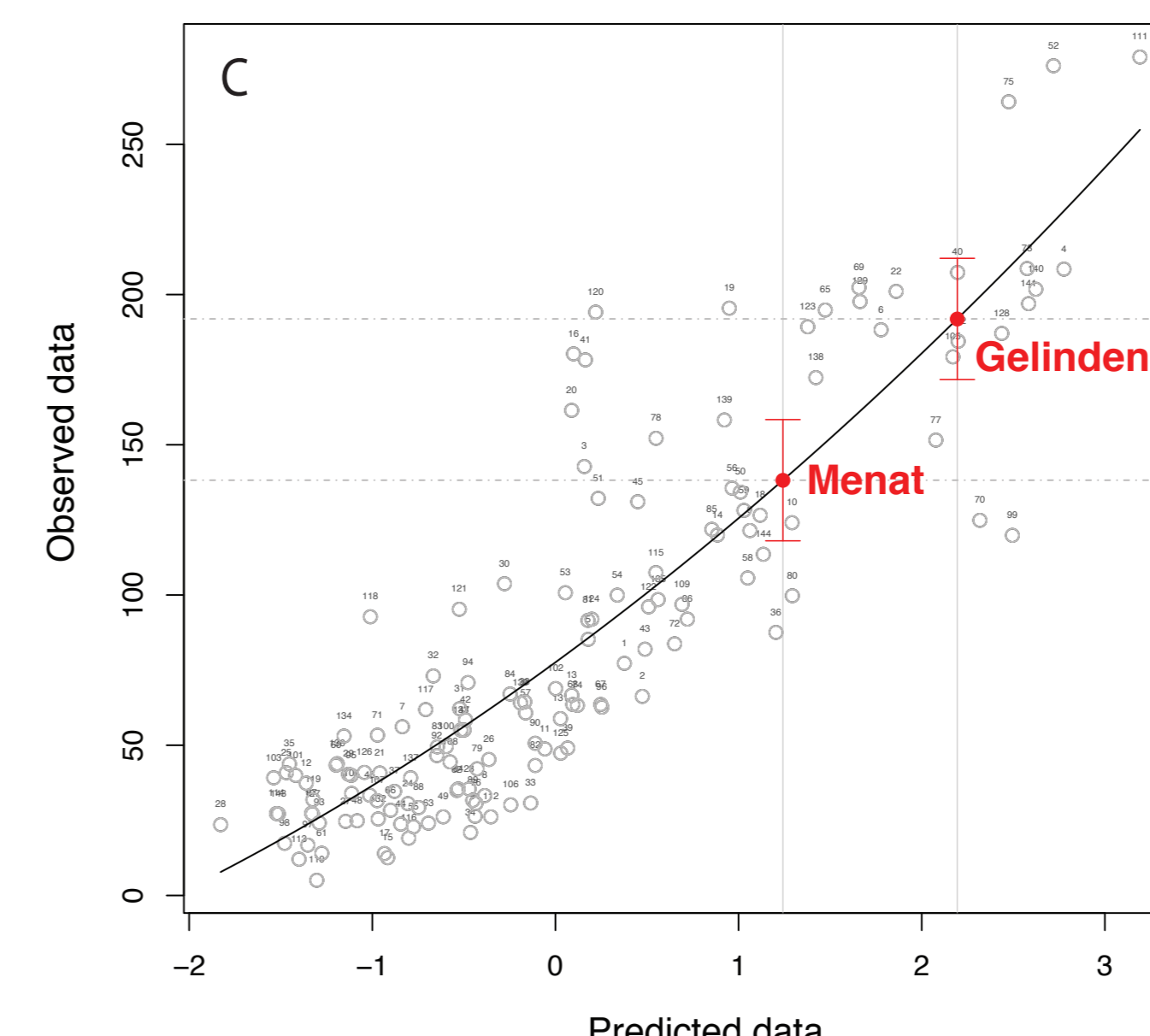
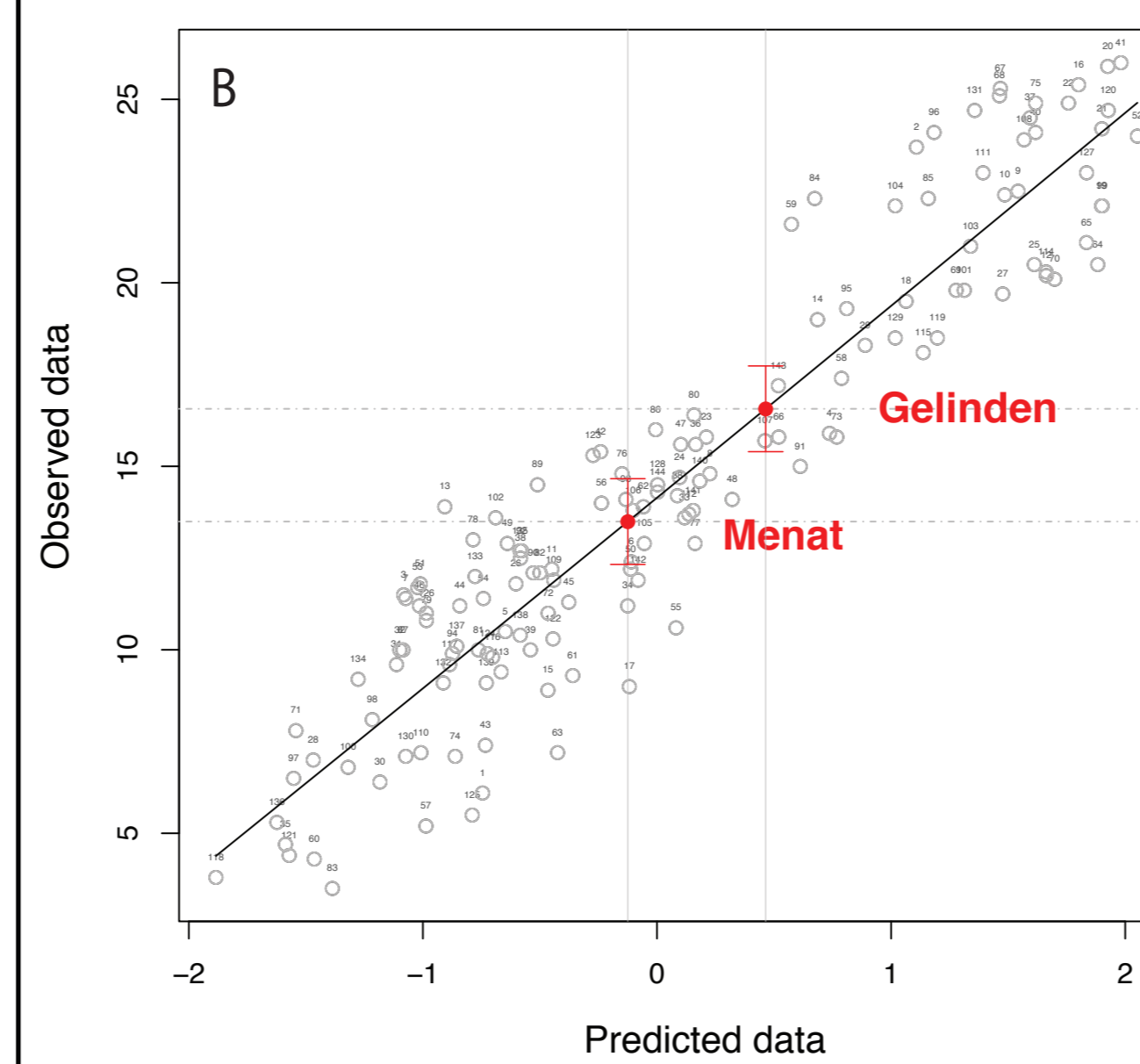


Figure 5. CLAMP results for Menat and Gelinden. A: CCA, B: vector scores MAT, C: vector scores GSP.

Table 1. Climatic parameters for Menat and Gelinden (CLAMP). Standard deviation in brackets. 3DRY/3WET: cumulative precipitations of the three driest/wettest months.

	Menat	Gelinden
Mean Annual Temperature (°C)	13.5 (2.1)	16.6 (2.1)
Cold Month Mean Temperature (°C)	2.9 (3.4)	7 (3.4)
Warm Month Mean Temperature (°C)	24.9 (2.5)	26.5 (2.5)
Growth Season Precipitation (mm)	1382 (31.7)	1919 (31.7)
3DRY (mm)	203 (5.9)	243 (5.9)
3WET (mm)	726 (22.9)	867 (22.9)
Length of growth season	8	9

Climate of western Europe during Paleocene. — According to the Köppen-Geiger climate classification, Gelinden and Menat paleofloras were under a warm-temperate/subtropical climate, without real dry season (Cfa type, tab. 1 & 2; fig. 6). Temperature seasonality is observed: mild winters (no frost), thus allowing the presence of evergreen taxa in both localities and hot summers.

Menat climate was colder and drier than Gelinden (fig. 5B-C, tab. 1). Local climatic differences during mid to late Paleocene are plausible. However, this difference could also be the result of (1) difference of age, (2) taphonomy. Until now the layers bearing fossil leaves in Menat have not been accurately dated, thus the relation with the cooling event of mid-Paleocene is difficult to estimate. The number of morphotaxa described in Menat is much higher than in Gelinden. This difference could be associated with a consequent transport in Gelinden, while Menat paleoflora reflects a more local environment. Transport could explain the lower completeness score of Gelinden (0.62), versus Menat (0.83). In this case, a selection of tropical coriaceous entire-margined leaves against deciduous toothed leaves, could lead to higher temperature estimates.

Overall, our results are consistent with previous results for middle to late Paleocene in China, also based on fossil floras and indicating rather warm temperate conditions (Quan et al., 2012). This is in favour of milder climates at middle latitudes during this period as compared to higher latitudes, where a more cool temperate climate was recorded, e.g. in New Zealand and Antarctica (Kemp et al., 2014), or in North America (Wilf, 2000).

Table 2. Temperature and precipitation criteria of Köppen-Geiger climates classification.

	Temperature	Precipitation
A - Tropical	Tcold > 18 °C	Rdry > 60 mm
B - Arid/dry		MAP < 10 x (2 x MAT + 14)
C - Warm temperate/humid subtropical f - without dry season w/s - with dry season	Tcold < 18 °C Tcold < 18 °C	Rdry > 40 mm Rdry < 40 mm
D - Cold/temperate continental	Tcold < -3 °C	

World map of Köppen-Geiger climate classification

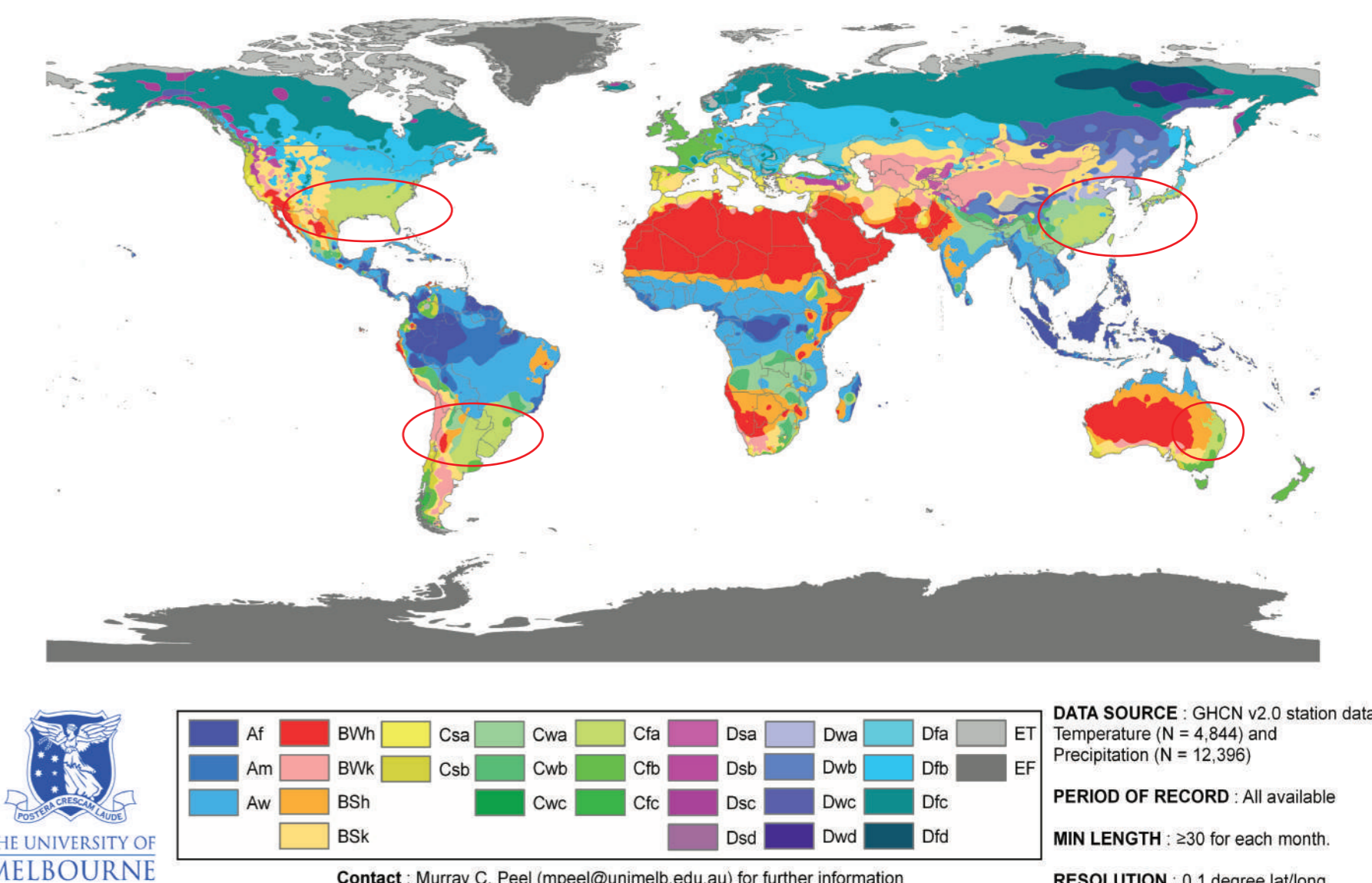


Figure 6. Köppen-Geiger climate classification. A: tropical, B: arid/dry, C: temperate/humid subtropical, D: cold/temperate continental, E: polar.

CONCLUSIONS AND PERSPECTIVES

Our study indicates warm temperate / subtropical conditions during Paleocene in Europe. This climate is consistent with previous interpretation of the vegetation based on taxonomy (broad-leaved evergreen forests) and it indicates mesothermal conditions rather than megathermal (equatorial). This result shows that «cooler» conditions prevailed during mid-Paleocene, as compared to the tropical climate of late Paleocene - early Eocene.

Slight differences were observed between the two localities and further studies are needed to unravel the significance of this climatic variation. Paleoclimatic study of historical collections is challenging due to disconnection from geological settings. Taphonomic studies, if possible, would be necessary to fully understand the climatic signal registered in the fossil flora of Gelinden and Menat.